NATIONAL BUREAU OF STANDARDS REPORT

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AN AUTOMATED EARTH TEMPERATURE STATION (INSTRUMENTATION)

Final Report

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NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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AN AUTOMATED EARTH TEMPERATURE STATION (INSTRUMENTATION)

Final Report

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An Automated Earth Temperature Station

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ABSTRACT

In order to improve heat transfer information needed for underground installations, the Environmental Engineering Section of the National Bureau of Standards has collected hourly earth temperature data for about a year at its site in Gaithersburg, Maryland. Temperatures were recorded at several depths under five different types of earth surface conditions; paved-asphalt in color, paved-painted white, bare ground, grass covered, and an occasionally mown area that is covered by naturally grown grass. Hourly measurements of earth temperatures at selected depths, ground surface heat flux, soil moisture content, ambient air temperature and relative humidity, solar radiation, wind speed and direction, and rainfall were collected using an automatic data acquisition system.

This report describes, in detail, the instrumentation system used. Included are the characteristics of the transducers, the data logging apparatus, the data transmission scheme and the data processing technique using a computer.

A later publication is planned to present detailed data and results obtained.

1. Introduction

The use of an automatic data acquisition system is currently becoming increasing advantageous because of the accessibility and efficiency of computers for processing a large amount of data. There is a great deal of discussion about automatic data acquisition systems, but many environmental scientists and engineers have not been exposed to the several technical problems associated with this modern equipment. Manufacturer's literature are usually presented in summary form for multi-purpose use and sometimes confuse those who must plan specific experimental projects using an automated data acquisition system.

Modern electronic instruments are quite sensitive to their operating environment and full time attention of an experienced operator is usually required. When a system is operating correctly it will produce an enormous amount of data but if not properly planned for it can overwhelm the experimental analysts. Moreover, data acquisition systems are becoming more and more sophisticated with new models constantly being introduced. The latest models can incorporate a computer programed to control the entire experiment including reduction of the data collected.

The purpose of this report is to describe in detail a simple and relatively unsophisticated automatic data acquisition system which was used at NBS in an earth temperature experimental project. Although the system is now a few years old, its basic principles and operation are the same as those of today's more complicated and computerized systems.

This report is intended primarily for those considering the use of this type of system and is therefore expository in nature rather than presenting a concise summary or only unique features of an automatic data acquisition system. Major emphasis is given to the explanation of the several specific aspects of automatic data handling. A brief statement of the objectives of the NBS earth temperature measurement project, to which this particular data acquisition system was addressed, is given in the next section as background.

2. Background

Since July, 1968, hourly observations of earth temperature and surface weather data have been collected at a site on the grounds of NBS Gaithersburg campus (77° 13' longitude and 39° 8' latitude, elevation 420').

The purpose of this data gathering effort was to provide improved earth temperature information pertinent to the design and evaluation of the Office of Civil Defense (OCD), Department of Defense below grade installations.

Previous studies conducted at the National Bureau of Standards revealed that the heat absorbing capacity of the earth surrounding an occupied underground survival shelter is a crucial factor for the maintenance of a tolerable shelter temperature. This was found to be especially true during a summer season during a prolonged and "sealed-up" condition. The heat absorbing capacity of the earth is in turn governed by its initial temperature at the time of the shelter occupancy called here its undisturbed condition.

An extensive literature search was conducted for data on earth temperatures and ground heat transfer. This search revealed that:

1. The availability of earth temperature data to depths beyond 5 ft is extremely limited. There is a need for reliable temperature data at greater depths for heat transfer analysis of underground installations.
2. The effect of earth cover on temperature at several depths was not explored on a long time basis. It was anticipated that there may be an effective way of controlling the earth temperature by the proper selection of earth surface covers.

3. Correlations involving earth temperature changes with surface weather characteristics, such as air temperature, humidity, solar radiation, rainfall and soil moisture are rare. This is primarily due to a lack of data recorded simultaneously on an hourly basis at any single weather station in the United States.
4. Earth temperature data currently published apply largely to undisturbed earth remotely located from nearby installations. Except for a few cases, the effect of nearby buildings upon earth temperature has not been well explored.
5. Data on the effects of the presence of ground water upon the earth temperature was not evident in the literature studied.
6. An analysis of earth temperature measurement error for a practical probe (strong enough to withstand rough treatment during the installation and transportation) was not revealed.
7. Use of automated data acquisition and processing by modern digital equipment for collection of earth temperature data was not reported.

8. As a result of previous studies several unpublished comments indicating the presence of stray ground electric currents affecting or overriding the actual emf developed in thermocouple circuits were revealed.

The objective of this investigation was to develop information concerning the eight points listed above. Major emphasis was placed on determining the effect of earth cover on the seasonal variation of temperatures at different depths. A second, equally important, objective was to study of the hourly change of near-surface soil temperature as it is affected by atmospheric conditions above it.

A major reason for the lack of this type of information is that collection of a vast amount of data is required over a period of at least one year to cover all seasons. This entails a considerable expenditure in terms of instrumentation and man-hours. However, the introduction of computers and automatic data acquisition devices made it feasible to undertake such experiments at less cost and with fewer man-hours than would have been required previously.

3. Description of Earth Temperature Site

The site designated for installing temperature probes was chosen to be approximately 500 ft away from the nearest building (Figure 1). As shown on a topographic map (Figure 2) the ground surface slopes down toward west at a grade of 1.25, providing good drainage. Core boring samples from depths of 1 ft to down to 30 ft revealed that the soil is of yellow silt; its average dry density and moisture content being about 100 lb/ft^3 and 15 percent of the dry weight, respectively. The moisture content of the surface soil was higher than that of the deep soil. It was 24 percent by weight. (See the soil test results attached.)

Two wells drilled to a depth of 30 ft in the vicinity of the temperature measurement site showed no trace of ground water throughout the test period. Five square patches each 50' x 50' were selected for five different surface covering treatments, as indicated in Figure 2. The surface conditions were: No. 1, paved asphalt (5" thick) with natural asphalt color; No. 2, asphalt paved (5" thick) and painted white with highway paint (Federal Spec. 8010-900-2936); No. 3, bare ground; No. 4, grass covered but periodically mowed; and No. 5, grass naturally grown. Each square patch is separated from the neighboring patches by a distance of 50 ft. A 4" diameter x 30' deep hole was bored at the geometric center of each patch. A temperature probe was installed in each hole. The soil brought out during the boring was backfilled and compacted around the temperature probe, as close to the condition of the original undisturbed soil structure as was possible.

4. Earth Temperature Probes

Each of the five temperature probes contained twelve pairs of #24 (AWG) copper-constantan thermocouples assembled as shown in Figure 3C. Each thermocouple wire was insulated with polyvinyl chloride plastic and was manufactured as duplex wire by the Thermoelectric Company. Seven of the twelve thermocouples were centered in a water-tight polyethylene tube of 1" outside diameter and 1/16" wall thickness. The thermocouples were located along each tube to correspond to depths indicated in Figure 3. Ottawa sand was used to fill the void around the thermocouple in the polyethylene tube. Five thermocouples were used for depths less than 1' and branched out from the main body of the probe to spread out horizontally around the probe at depths as illustrated in Figure (3-A).

In place, the main vertical probe housing curved horizontally at the 1' depth and extended about 51" to an underground junction box. This was done to minimize stem heat conduction error for shallow temperature measurements. The tip of each of the five shallow thermocouples were protected from direct contact with the soil by rubber sealant caps. This was done to isolate the thermocouple circuit from any ground loop electric circuit, which would have caused serious common mode problems as described later. Protection of the thermocouples within the polyethylene tubes and rubber sealant caps could cause error when measuring earth temperature because such an arrangement prevents the thermocouples from direct contact with the soil. However, these protection measures were considered to be necessary to minimize not only the effect of ground loop current but also to minimize mechanical damage of thermocouples during transportation and installation especially for an experiment of this nature.

In order to determine the measurement error due to the protective coverings around the thermocouples a laboratory investigation was made on two vertical probes: one with a stainless steel tube and the other with a phenolic tube.

Figure 4 shows a sketch of the probes which were separately installed in a sandbed as illustrated in Figure 5. The sandbed was in an 18 1/4" diameter drum 26" high insulated circumferentially with a 7" thick fibrous glass blanket to simulate the adiabatic boundary condition found in the earth. Figure 5 shows the locations of the thermocouples with those within the protective probe matched exactly in depth with those installed directly in the surrounding sand at distances of 6 1/8" and 3 1/8" from the center of the probe. To simulate daily ground surface temperature fluctuations two 250 watt heat lamps were energized during working hours, 8:30 a.m. to 5:00 p.m., and were off during the remaining hours of the day. The on-off cycle was maintained for a period of seven days to attain a steady periodic cycle.

Figure 6 shows sample results obtained from this investigation. Temperature data obtained from the probe thermocouples are compared with data from thermocouples installed directly in the sand 6 1/8" away from the probe. Figure 6 shows that readings from the probe thermocouples closely reflect actual depth sand temperatures for depths more than 12". This data is for a conductive stainless steel probe protruding above the sand surface and directly exposed to radiant heat. The temperature deviations between the thermocouples in the phenolic probe and those in the undisturbed sand were found to be even smaller than those for the stainless steel probe as given in Figure 6A. It is concluded that the manner in which the actual thermocouple probes were installed, as illustrated in Figure 3, yields very small errors due to the stem heat conduction and to the thermal insulating effect of the protective tubing.

Theoretically, probe stem heat conduction error becomes smaller as the thermal diffusivity of the probe material approaches the soil thermal diffusivity. The typical soil thermal diffusivity is 0.02 ft^2/hr, whereas those of stainless steel, phenolic, polyethylene and sand are respectively 0.172, 0.004, 0.06 and 0.01.

From the standpoint of thermal diffusivity and for practical reasons a polyethylene-sand filled probe was selected. A practical advantage of the polyethylene probe is that it is not rigid, and thus can be transported in coiled form as compared with a long rigid rod. Moreover, with sand inside the tubing it becomes heavy enough to allow easy insertion into a vertical hole in the ground.

Horizontal thermocouples for shallow depth temperature measurements were installed at the bottom of a 1/4" wide groove at the depth indicated along the rays shown in Figure 3A. The narrow groove was then backfilled with the surrounding soil. In this manner the earth was least disturbed and the depths of the thermocouples were controlled very accurately.

5. Junction Box and Underground Cable

In addition to thermocouples, soil moisture gauges and heat flow transducers as described in sections 7.6 and 7.3, respectively, were installed around the thermal probe as shown in Figure 3. The lead wires from all of the transducers for each patch were brought to an underground junction box. The box was 12" long, 8" wide and 6" high and was made of galvanized cast iron. This box contained all waterproof connections to the underground cables leading to the instrument bunker. Figure 3C shows a schematic diagram of junction box terminals for the various transducers. Each junction box was sealed with a rubber gasketed lid and inlets to the box were well sealed with a silicone rubber compound (Dow Corning 732 RTV Silastic).

Each underground cable contained 21 individually insulated, labelled, solid conductors all #24 A.W.G.; 16 were copper and 5 were constantan. All wires were enclosed in a thick polyvinyl-chloride cover to form a cable considered appropriate for an underground installation. The manufacturer of the multi-conductor cable was the Thermoelectric Company. A cross section of the underground cable is shown in Figure 3C. The wires were arranged for easy identification.

Patch #3, bare ground surface, was provided with two sets of junction boxes and underground cables, because it contained 7 more thermocouples and three more heat flow transducers than the other four patches. The extra thermocouples were purposely installed unprotected and were placed outside the polyethylene probe to allow a check on the magnitude of error introduced to unprotected thermocouples. The standard heat flow transducers for all patches were installed at the 4" depth except at Patch #3 as discussed in section 7.3.

Figure 3D shows the manner in which the underground cables were connected to the instrument bunker via 24" deep ditches.

6. Underground Instrument Bunker

A special underground instrument bunker was constructed to house the temperature measuring station. Construction features and the interior facilities of the bunker are schematically in Figure 7. All but the teletype unit of the automatic data acquisition system were housed within this bunker. Some of these instruments were temperature sensitive and the bunker was air conditioned during the summer season to keep the temperature below 90 °F and relative humidity below 50%. A 1/4 ton nominal capacity condensing unit was installed above the bunker with a ceiling mounted cooling coil inside the bunker. About one gallon per week of condensate was collected during a summer week. The bunker entry was a vertical hatch covered by a lightweight manhole cover. A telephone system between the instrument bunker and a laboratory module at NBS was used to transmit data from the bunker at a teletype unit in the laboratory. This telephone line was also suitable for voice communication.

The exterior surfaces of the bunker walls were well waterproofed but waterproofing around the incoming bundle of six underground cables was especially difficult to obtain. Initially rain water found its way into the bunker through this opening in the wall.

Water leakage after the first heavy rain flooded the bunker floor to a depth of 12", causing considerable damage to several critical instruments, such as the data transmission sets, thermocouple reference junctions, and wind data signal conditioners. Several transformers in other instruments were also damaged apparently due to the effects of this electrical storm.

Thunderstorms were also a cause of data transmission failure. A lightning rod was later installed over the instrument bunker atop the wind tower and this helped decrease the number of data transmission failures during thunderstorms. Whenever data transmission fails, the system must be manually restarted.

7. Transducer Systems

Table 1 shows data channel identification numbers to each transducer. There was a total of 78 thermocouples, eight heat flow meters, two solar pyronometers, plus transducers for wind speed, wind direction and rainfall. A special transducer for ultraviolet radiation data was used for a limited time period for the Building Materials Section of NBS. This Section operates an outdoor weatherability study station in the vicinity of the earth temperature station.

7.1 Temperatures

The majority of the 78 thermocouples were for soil temperature measurements. Thermocouples were located at depths of 30', 20', 10', 6', 4', 2', 1', 12", 4", 1", and 0". The 12" depth temperatures were obtained using two thermocouples.

For Patch #3 the temperatures at depths of 30', 20', 10', 6', 4', 2', and 1' were repeated using channels 37 through 43 in addition to the regular thermocouples which occupied channels 25 through 36. The seven additional thermocouples installed in patch #3 were unprotected in the earth along the outside of the probe to study the effect of ground loop electric leakage (common mode noise).

Thermocouple channels 68 through 75 were designated for temperature measurements in and around the underground instrument bunker. Because the bunker houses electrical instruments which generate heat, and since the thermal environment of the instrument bunker itself is important the thermocouples were placed to measure the inside surface temperatures, ground temperature surrounding the bunker, and air temperature above it (Figure 8).

Channels 76 and 77 were assigned for measurement of dry-bulb and wet-bulb temperature of air unaffected by radiation from the sky and the ground. As shown in Figure 8 these two thermocouples were installed in a ventilated birdhouse-like enclosure 4' above the ground (standard Weather Bureau Instrumentation), where the outdoor air is force-ventilated through the enclosure using a small fan. The wet-bulb thermocouple was attached to a metal washer 1/8" in diameter which was inserted into a wet wick. Capillary action kept the wick wet continuously because the other end of the wick was in a plastic bottle containing distilled water. This scheme was recommended in reference [7]. The thermocouple connected to Channel 78 was for measurement of the temperature at a 12' height where wind transducers were installed (Figure 8).

7.2 Solar Radiation

Channels 79 through 82 were assigned for pyronometers (180° total solar radiation) to measure direct and diffuse radiation. Only channels 80 and 81 were used and these were connected to shaded and unshaded pyronometers (Epply type), respectively. The calibration of the pyronometers for the shaded application was done at the Epply laboratory whereas the pyronometer for the unshaded application was calibrated at the ESSA laboratory. Solar radiation is very important in the evaluation of the ground surface effect upon the earth temperature beneath it.

Since the temperature measuring site had no natural shade, the total hemispherical radiation measured by the pyronometer is considered most meaningful. Shaded pyronometer measurements were collected simultaneously to obtain data on diffuse sky radiation and to check theory relating direct radiation and diffuse sky radiation. Direct radiation is the difference between the total hemispherical and the diffuse sky radiation.

Since the total hemispherical radiation fluctuates very rapidly during a cloudy day, particularly when the clouds are moving rapidly between the sun and the sensor, a once-an-hour observation of the instantaneous reading of the pyronometer is not as meaningful as an average reading that is based upon an integrated measurement over a one hour period. Such a long-time integrating device was not available at the start of this experiment but has just recently become available. It is recommended that for future data logging operations of this nature a long-time integrator be used to obtain what is essentially fluctuating data. This would apply to the variables of solar radiation, wind velocity, heat flux and possibly others.

7.3 The Heat Flow Data

Channels 85 through 92 were connected to heat flow transducers obtained from the National Instrument Laboratory, Inc. type no. HF3. These transducers are polyvinyl discs 0.16" thick and 4.3" in diameter and were considered suitable for the underground installation. The manufacturer's calibration constants were used for the application of these heat flow meters.

Except for patch #3, all the heat flow meters were installed at depth of 4". Heat flow was measured at 18", 12", 4" and 2" depths for patch #3 to study the effect of earth cover as combined with other parameters upon the ground heat transfer.

7.4 Wind Data

A wind direction and velocity transducer, type C, which was made by the Belfort Instrument Company, was assigned to channels 83 and 84 respectively. The wind velocity transducer is of the dynamometer type and its DC voltage outputs were calibrated against known air velocities in the wind tunnel of the National Bureau of Standards. The calibration curve is shown in Figure 9. This transducer was installed atop a 12' tower as shown in Figure 8.

The wind direction transducer is of the vane-type. The particular transducer employed for this study was so designed to make eight switch contacts at the base of the van shaft corresponding to the eight wind directions; N, NE, E, SE, S, SW, W and NW.

A signal conditioner, shown in Figure 10, was designed and constructed to generate eight different DC voltage levels corresponding to the above eight wind directions. Table II shows the calibration data as voltages vs. wind direction.

7.5 Rain Gauge

Channels 94 and 95 were assigned for collection of rainfall data. The rainfall transducer was made by Belfort Instrument Company, Catalog No. 5915 (Figure 11). It consists of a galvanized bucket placed on a weighing mechanism, which converts the weight gain of the bucket due to accumulated rain into a change of electrical resistance. Figure 12 shows the calibration curve provided by the manufacturer relating the electrical resistance to inches of rainfall. Before use, the calibration curve was checked for its accuracy at the points indicated by solid triangles. Since, as mentioned later, the data acquisition system employed for this project did not have the capability of reading the electrical resistance directly, a signal conditioner to convert the resistance change to a mV signal, Figure 13, was devised. In Figure 13 the equation indicated was used to obtain the number of inches of rainfall from the DC signals sent to channels 94 and 95.

7.6 Soil Moisture Transducers

Although not connected to the automatic data acquisition system, the soil moisture content was monitored concurrently with the collection of other data but readings were taken only once a week because change of moisture content was extremely slow. The moisture content transducers (Soil Test Inc., MC310A) were installed at the depths of 4" and 12" at all patches except Patch #4 where the soil moisture gages were located at depths of 30', 20', 10', 6', 4', 2', and 1'. The moisture sensor was made of parallel sheets of electrode mesh separated by a thin glass fiber cloth (Figure 14). This thin material very quickly establishes a moisture equilibrium with the surrounding soil. When an AC voltage is applied to the electrode current leaks through the glass fiber cloth in proportion to its moisture content. These gages require calibration for the specific type of soil in which the gauges are to be used. Thus a calibration curve of AC current versus a known soil moisture content must be obtained. NBS laboratory tests using the soil of the temperature measuring site show reasonably good correlation between the moisture meter reading and the soil moisture content.

There are many other types of soil moisture gages. It was found that the particular transducer employed in this project was satisfactory especially from the standpoint of use with an automatic data acquisition system. A primary requirement for a soil moisture gage was that it should be fast in response yet remain very stable over a long period of time, and also that its signal output must be compatible with the automatic data acquisition system.

8. Data Acquisition and Processing System

8.1 Overall System

Figure 16 shows the overall data flow diagram of the acquisition and data processing system employed in this project. The data acquisition system was assembled by Keltec Industries on contract and consists of a scanner, a digital voltmeter, and a TWX coupler. The NBS specification for this system is attached as Appendix 1 of this report. Signals from the several transducers were fed to the scanner as analog signals (i.e., not in the form of digits). Transducers were automatically scanned once an hour using a Cunningham cross-bar scanner, 309G. The analog signals were then digitized using a Vidar, integrating type digital voltmeter Model No. 520. The integrating digital voltmeter (IDVM) keeps its reading gate open for a period of one second and then creates a digitized mV value corresponding to the 1 second average of the signal from the channel being scanned. The digitized data thus created is said to be of a parallel form because the numerical values converted into binary digits are presented in a string of parallel bits.

Since the parallel bits are in a BCD* format they are then converted into a serial format by the Keltec TWX coupler. This is done to allow the data to be transmitted via a telephone line to a recorder, bit by bit.

The data as a string of serial bits is transformed using a transmitting data set into tones which modulate the base frequency of the telephone line (a standard technique used by the telephone company). The frequency modulated telephone tone signal travels via an underground telephone line to a receiving data set which demodulates the message to the original serialized digital format. The signal then goes to teletype unit, 33TU, located in Room B307, Building 226, of NBS. The teletype unit prints out the data and simultaneously punches the same data on a reel of paper tape. The data on punched paper tape can be read onto a magnetic tape later using the NBS Digidata 1720 paper tape to magnetic tape device. This conversion from paper tape to magnetic tape procedure could have been eliminated, had the NBS computer system, UNIVAC 1108, been able to read the punch paper tape. Unfortunately this capability was not available. The magnetic tape thus produced is then read, bit by bit, with the use of a special computer program called CHAR(N).**

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* BCD (Binary Coded Decimal) will be explained in detail later.

** Listings of all of the computer programs mentioned hereafter are attached at the end of this report.

Another, and a major computer program called SOIL then reconstructs the original DC voltage data and converts it into meaningful engineering information. If desired, the data thus processed through SOIL may be presented in graphic form. The processed engineering data are also stored on magnetic tape for further mathematical and statistical analyses. These analyses will be the subject of a separate report.

8.2 Scanner and Its Control

The scanning or multiplexing of the transducers described in previous sections was accomplished using a Cunningham cross-bar type scanner. The cross-bar is a system of relays designed to open and close the switches rapidly in a desired sequence. The scanner is capable of switching 600 single wire circuits, which can be made into three different modes, namely, the 100-6 pole, 200-3 pole circuits, 300-2 pole circuits or 600-1 pole circuits. The intermixing of these four modes is usually difficult. Since the earth temperature study project was concerned with about 100 channels, the 6-pole mode was adopted; but only three wires per channel were used.

Figure 3 shows how the three wire terminals were connected to the various transducers.

When selecting a scanner, the following specifications are pertinent:

1. Open circuit insulation between switching conductors: more than 10 K Ω at 0-50% RH, -10 °C - +40 °C at 500 VDC
2. Maximum contact resistance: less than 0.3 ohm
3. Breakdown voltage: 1000 VAC
4. Current carrying capacity for non-inducing load: 100 mA at 50 VDC
5. Channel crosstalk: less than 60 db at 5 mega hz with 100 ohm circuit impedance

The scanner is required to possess very high leakage resistance and low shunt capacitance in order to allow high source impedance and/or high frequency input to be switched without the degradation of the transducer signals.

It is recommended that each channel be individually guarded and floated* so that the capacitance between any guard and the measurement pair be extremely small (less than 1 pf). The crosstalk noise, mentioned in the specification, is the spurious voltage reading superimposed on the source signal circuit. The noise is the leakage across two channels and is usually expressed in db, based upon the following equation

$$\text{Crosstalk noise} = 20 \log_{10} 2\pi fCR$$

where f, C and R are noise frequency, interchannel capacitance and source impedance, respectively.

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* None of the parts of the circuit are grounded.

8.3 Integrating Digital Voltmeter

The heart of the automatic data acquisition system is the integrating digital voltmeter (IDVM), which accepts the analog signals and digitizes them for display as well as for further automatic processing.

Although detailed explanations of the IDVM operation can be found elsewhere it is important that the environmental engineer understand some of the unique features of its operation. Most of the IDVMs combine a voltage-to-frequency (V-F) converter with an electronic counter. The V-F converter produces electric pulses at a rate proportional to the analog signal. The counter then totals the pulses for a selected period of time, providing a reading equal to an integrated average of the input during the measurement period. This integrating capability helps to decrease error due to superimposed AC noise when measuring a DC signal. When the AC noise ripple becomes large, however, the peak value of the ripple signal goes through zero and requires the electronic counter to count down (Figure 17). Many inexpensive integrating digital voltmeters do not have the capability of counting down as well as up. When the use of the up-and-down counter is not possible, the input AC ripple noise should be made sufficiently small by other means such as guarding. This will be described later. IDVM employed in this research had no up-and-down counter and the counter frequently became overloaded when AC noise was superimposed on the channel signal the magnitude of the noise being much larger than the DC signal being measured.

The important features to be considered when selecting an IDVM for earth temperature measurement are, its ability to read low level signals of less than 5 mV, a high AC noise rejection capability, a high input impedance, accuracy and resolution, and stability with respect to ambient temperature and time.

In order to understand the requirements for the proper functioning of the IDVM, it is advantageous to know some basic characteristics of voltmeters to be used for measuring low-level signals, such as the output of thermocouples. There are two important kinds of voltage measuring devices; one is a bridge balance or potentiometric type and the other is the current drawing type. The potentiometric type is based upon the null-detection of a galvanometer in a Wheatstone Bridge circuit, as shown in Figure 18. When the bridge circuit is completely balanced, there is no electric current flowing across the transducer circuit. As will be described later, most voltage measurement errors come from current flowing across the transducer circuit. The potentiometric voltmeter, therefore, is regarded as the most accurate type of voltmeter when a stable source DC signal is measured. Unfortunately, however, the bridge balancing and null-detection does not lend itself to high speed, automatic data acquisition, although high speed is not a requirement for this particular investigation. Most of the automatic voltage recording devices, both analog and digital, are current-drawing types, or they rely on a minute current in the transducer circuit to drive the meter. There are many cases where the current drawn by the voltmeter presents enough voltage drop in the transducer circuit to cause substantial error. Figure 19 shows a schematic diagram of the non-potentiometric voltmeter circuit and indicates an equation relating the actual voltage Vs, developed by the thermocouple to V, the voltage indicated on the voltmeter when the transducer circuit impedance and the voltmeter impedance (input impedance) are R_s and R_n, respectively. In order for V and V_s to be very close, the input impedance R_n of the non-potentiometric voltmeter should be many times greater than the source or transducer circuit impedance R_s $(R_s/R_n \approx 0)$.

For the earth temperature instrumentation, the thermocouple circuits are usually small gauge (#24) and very long (600 ft) resulting in a large value of R_s. The measured thermocouple circuit resistance for this project was on the average 300 ohms. The input impedance of the voltmeter should, therefore, be not less than 30 K, if 1% accuracy is desired. If the voltmeter has a relatively small input impedance a presimplifer should be used to increase the input impedance of the system.

8.4 Noise Rejection of Voltmeter

During the selection of a digital voltmeter, environmental engineers are often confronted with unfamiliar terminology such as common mode and normal mode rejection. And these terms are expressed in decibels (db)! It is important that these be correctly understood.

The common mode noise is generated by the AC line pickup, or hum, resulting from having two grounds in the system; one at the transducer and another at the chassis of the voltmeter (Figure 20B). The voltage difference, e_{cm}, between these two grounds induces a ground loop current at the AC line frequency and causes a voltage to appear at the voltmeter input which can easily be greater than the signal itself, yielding a completely erroneous reading. The degree to which this ground loop current is minimized depends upon the electric isolation between the transducer circuit and the voltmeter chassis. Use of a heavy ground bus or shielding of the transducer cable is usually found ineffective for decreasing the common mode pick up, and sometimes it is even found to increase it. Most of the modern digital voltmeters are, however, of guarded construction and have a very high common mode noise rejection capability.

Figure 21 illustrates unguarded and guarded voltmeters and the manner in which ground loop current flows through the transducer circuit. Included in the same figure is mathematical formula for evaluating the common mode noise rejection capability as a function of noise frequency f, capacitance, C' between the transducer circuit and the voltmeter chassis, and the impendance R of the transducer circuit. According to this equation, the noise rejection of 160 db means that the noise voltage induced in the transducer circuit due to common mode voltage of 100 V is on the order of 1 microvolt. The noise rejection capability of the voltmeter decreases by 20 db with the tenfold increase of any one of f, C' and R.

The normal mode noise, on the other hand is generated by electric appliances, radios, and TV's. It will be superimposed on the source signal in the transducer circuit, as shown in Figure 20A. A conventional way to minimize the normal mode noise pickup is to shield the transducer lines. The normal mode noise can, however, be rejected completely by the integrating process when a whole number of noise cycles is averaged over a given sampling or integrating period such as illustrated in Figure 22. If a portion of the noise cycle is left out of this averaging process (as shown in Figure 23A), an error will be produced. A maximum value for this error is indicated in the figure. The magnitude of error thus generated will decrease as the noise frequency increases, becoming zero every time the noise frequency becomes an exact multiple of the sampling frequency (Figure 23B). If the sampling period is 0.0166 seconds (60 Hz), the normal mode rejection becomes infinity for noises of 60 Hz, 120 Hz, 180 Hz, 240 Hz, etc. Therefore, except at this peak noise rejection, the normal mode noise rejection generally increases by 20 db when the frequency of the noise increases by a decade, an opposite of the common mode noise rejection.

As indicated earlier, the common mode noise rejection capability of a digital voltmeter decreases to 20 db per decade increase in noise frequency, resulting in the generation of normal mode noise on the transducer output. The normal mode noise rejection capability increases at the same rate. The combined noise rejection curve is illustrated in Figure 24.

8.5 TWX Coupler

Before the digital data produced in the IDVM are transmitted through telephone lines, the data must be converted into a suitable form. The TWX coupler is designed to accept data in a BCD (binary coded decimal) form and it is presented to the coupler in parallel form, i.e., all digits are presented at the same time. The TWX coupler stores the data, translates it into ASCII format (Figure 25) and serializes it for a bit by bit transmission through telephone lines. The coupler also initiates the scanning cycle for a preset time interval such as 30, 60, 120 and 240 minutes.

8.6 Data Carrier Set (Modem)

The digital data as serialized by the TWX coupler is frequency modulated on a carrier wave of 765 Hz by a transmission unit in the Data Carrier Set. The signals converted into tones are carried via telephone lines to a receiving unit of the Data Set and demodulated to a digital format. The Data Set employed in this project was Stelma IBTCU/IBRCU and had a data carrying speed of 150 band (bit per second).

Since each ASCII character is made of 8 bits, the character transmission should be approximately 20 per second. And since the data for each channel consists of 12 characters, approximately 2 channel data will be transmitted per second.

8.7 Teletype Unit

Data coming from the receiving unit of the data set are assembled, converted into decimal digits, printed in page format and simultaneously punched in a paper tape in ASCII code by the teletype (Model 33) as shown in Figure 26.

The printout of the teletype is also shown in Figure 27. The printing and punching speed of the teletype unit is 10 characters per second.

Each channel of the 100 channels of information printed or punched out consist of 12 characters in the following sequence

Channel identification	3	characters
polarity	1	"
data	6	"
decimal location	1	"
space or carriage return	.	"

For example, if the channel information reads

060 + 0159677 △, (△ meaning a space)

the information contained in channel 60 is

$$+ 15967 \times 10^{-7} \text{ V or } 1.596 \text{ mV}$$

Since 100 channels were scanned and recorded at every hour, the total time required to complete the data recordings per cycle was

$$12 \times 100/10 = 120 \text{ second or two minutes}$$

The teletype unit was activated by a signal from the scanning system a few seconds before the data scanning started and remained activated approximately one minute after all the 100 channels of data were recorded. Timing control of the teletype unit was accomplished by a pulse communication device indicated in Figure 16.

The punch paper tape on the teletype unit comes in a roll that can record 10,000 sets of 12 character data. Since each scanning cycle produces 100 sets of 12 character data at the rate of one cycle per hour one roll of paper punch tape should be able to record 100 hours or approximately four days of data.

8.8 Processing of Paper Punch Tape

The punch paper tape from the teletype is fed to a paper-tape-to-magnetic-tape-converter (Digidata 1720). The tape converter reads the paper tape at a rate of 100 characters per second and writes on a magnetic tape at 200 characters per inch in even parvity. The format of the data frame on the magnetic tape is very similar to that of the punch paper tape.

Standard magnetic tape is usually 2400 feet long and should be able to contain 5,760,000 characters of character data.

Since one set of data consists of twelve characters and one scanning cycle contains 100 sets of data, one magnetic tape should be able to store approximately 4800 hours or 1/2 year of 100 channel information taken hourly.

The time required to produce a magnetic tape is 16 hours if operated continuously. As mentioned before, one reel of paper punch tape contains four days of information and requires approximately 20 minutes to convert into a magnetic tape of approximately 50 ft. The data structure in the magnetic tape is 170 logical words of 36 bits length, made into a block. A typical block listing is shown in Figure 28.

8.9 Data Processing on Computer

The magnetic tape produced on the Digidata 1720 is fed into a computer (UNIVAC 1108 at the National Bureau of Standards) at a rate of 150 in/sec or 2500 data/sec. A computer program called CHAR(N), the Fortran listing of which is attached in this report, reads the tape block by block and decodes the data, twelve binary characters at a time, to form BCD characters. The decoding scheme of the magnetic tape of CHAR(N) is illustrated in Figure 29.

The data decoded by CHAR(N) is processed through a computer program called SOIL to obtain engineering information. A Fortran listing of SOIL is attached to this report and Figure 30 shows a sample listing of one cycle of information converted into engineering data. This listing shows that channels 26, 41, and 59 are not operating properly. The columns headed by CHAN, MV, DATA and REMARK of Figure 30 represent the channel number, mV data acquired by the data logger, engineering data converted from the mV data, and appropriate remarks respectively. The remarks indicated are

T = temperature in degree F

SOL = solar radiation in Btu/hr, ft^2

WDD = wind direction

WDV = wind velocity in MPH

HF = heat flow in Btu/hr, ft^2

RAIN = rain data in inches of water

REF = reference temperatures

UVR = ultra-violet radiation

If desired, the data processed through the computer program SOIL can be presented in graphical forms such as illustrated in Figures 31 and 32.

9. Error Analysis

In addition to the stem conduction error of the probe containing the thermocouples, and the noise errors discussed previously, the following errors should also be taken into consideration when using thermocouples for earth temperature measurement.

9.1 Thermoelectric Error

This is an emf caused by having junctions of two dissimilar metals under an appreciable temperature gradient within the thermocouple circuit. When the junction of two dissimilar metals is unavoidable, an isothermal environment should be created around the junction.

9.2 Galvanic Error

The emf created by the electrolytic or galvanic effect is no small problem for ground temperature measurement. Thermocouple circuits should be kept dry and clean to minimize this problem, which means the complete protection of the transducer circuits from the moist soil.

9.3 Electrostatic and Triboelectric Effect

There are low frequency disturbances generated by electrostatic and triboelectric (charge of electricity due to friction) effect. When the user's body potential, is quite different from the ground potential, the voltmeter indicates erroneous signals with the approach of his hand.

9.4 Stability of the Voltmeter

The voltmeter accuracy is usually specified in ±% of the full scale within a limited temperature range (0 - 50 °C is very common), and for a certain time period. The drifting of the voltmeter reading due to the time and the ambient temperature change should be carefully monitored. A good way to check the voltmeter stability is to monitor its reference voltage, which is usually in a temperature controlled oven inside the voltmeter. Channel 000 of this system was connected to the reference source of one volt. The reading was 1.00028 volt in May, 1968 and has become 1.00097 in July, 1969, which is approximately +0.005% drift per month and thus considered extremely stable. The daily fluctuation of the reference source was practically unnoticeable. Stability and accuracy of the reference thermocouple junction are also important from the standpoint of converting the thermocouple emf to actual degrees Fahrenheit. The reference temperature junction used in this research for channels 1 through 67 was a 150 °F source manufactured by PACE Company. The manufacturer claimed that the temperature stability was ±1/10 °F and junction accuracy was ±1/5 °F. Similar stability and accuracy were claimed by the Joseph and Kays Company for their 32 °F reference junction used for channels 68, 75, 76, 77 and 78.

Since these reference junctions were shared by many thermocouple circuits, it is possible that the common mode errors introduced into one circuit would have influenced the others.

In order to evaluate the magnitude of the common mode error existing in the transducer system a comparative analysis was made of the readings for most of the transducers obtained by the integrated digital voltmeter and those obtained by a potentiometric analog voltmeter (Rubicon Honeywell 274G). As mentioned earlier, the potentiometric voltmeter should be devoid of all the errors due to the common and normal mode noises. Table 3 shows the comparative readings of these two voltmeters with the source impedance measured separately by an Ohmmeter (Simpson). Because of the time elapsed between the two sets of measurements and because the ground surface condition was rapidly changing, comparisons of shallow depth thermocouple data and particularly the heat flow meters readings are not meaningful. The deep thermocouples, however, show an average deviation of the IDVM reading from the potentiometer reading of approximately 7μV.

Table IV summarizes all of the possible errors discussed previously. A total temperature error corresponding to 52μV is 2.5 °F.

10. Summary

Instrumentation used in an earth temperature project at the National Bureau of Standards is described in terms of its application in an automated data acquisition and processing system. The major components of the data acquisition system are presented with particular emphasis on the principles and use of a digital voltmeter.

The several sources of error involving thermocouple circuits were analyzed. It was concluded that the precision of temperature measurement probable in this type of system is about ±2 °F consistent with previous experience.

This report is primarily addressed to the instrumentation in the system but sample results of earth temperatures and heat fluxes are included to illustrate the versatility of the automated digital data acquisition system.

The data was collected, processed and stored on magnetic tapes. An analysis of the data and results is planned for later publication.

11. Acknowledgment

The authors acknowledge with appreciation the invaluable assistance of the several people who contributed to this project especially Mr. J. D. Allen who was responsible for day to day operations.

USCOMM-NBS-DC

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14. Titles of Tables

Table I	Identification of Data Channels
Table II	Calibration Data for the Wind Direction Transducer
Table III	Comparison of the Readings Obtained by the Data Acquisition System and Those Obtained by a Potentiometric Bridge
Table IV	Summary of the Error Analysis

Table I

Channel No.	Sensor	Location
0	Reference Volt	Within the IDVM
1	Thermocouple	30 ft under Patch No. 1
2	"	20 " " " " "
3	"	10 " " " " "
4	"	6 " " " " "
5	"	4 " " " " "
6	"	2 " " " " "
7	"	1 " " " " "
8	"	12 in. " " " "
9	"	4 " " " " "
10	"	2 " " " " "
11	"	1 " " " " "
12	"	0 " " " " "
13	"	30 ft under Patch No. 2
14	"	20 " " " " "
15	"	10 " " " " "
16	"	6 " " " " "
17	"	4 " " " " "
18	"	2 " " " " "
19	"	1 " " " " "

Table 1 - Continued

Channel No.	Sensor	Location
20	Thermocouple	12 in. under Patch No. 2
21	"	4 " " " " "
22	"	2 " " " " "
23	"	1 " " " " "
24	"	0 " " " " "
25	"	30 ft under Patch No. 3
26	"	20 " " " " "
27	"	10 " " " " "
28	"	6 " " " " "
29	"	4 " " " " "
30	"	2 " " " " "
31	"	1 " " " " "
32	"	12 in. under Patch No. 3
33	"	4 " " " " "
34	"	2 " " " " "
35	"	1 " " " " "
36	"	0 " " " " "
37	"	30 ft under Patch No. 3
38	"	20 " " " " "
39	"	10 " " " " "
40	"	6 " " " " "

Table 1 - Continued

Channel No.	Sensor	Location
41	Thermocouple	4 ft under Patch No. 3
42	"	2 " " " " "
43	"	1 " " " " "
44	"	30 ft under Patch No. 4
45	"	20 " " " " "
46	"	10 " " " " "
47	"	6 " " " " "
48	"	4 " " " " "
49	"	2 " " " " "
50	"	1 " " " " "
51	"	12 in. under Patch No. 4
52	"	4 " " " " "
53	"	2 " " " " "
54	"	1 " " " " "
55	"	0 " " " " "
56	"	30 ft under Patch No. 5
57	"	20 " " " " "
58	"	10 " " " " "
59	"	6 " " " " "
60	"	4 " " " " "

Table 1 - Continued

Channel No.	Sensor	Location
61	Thermocouple	2 ft under Patch No. 5
62	"	1 " " " " "
63	"	12 in. under Patch No. 5
64	"	4 " " " " "
65	"	2 " " " " "
66	"	1 " " " " "
67	"	0 " " " " "
68	"	Zone Box within the Bunker
69	"	Inside Surface of the Bunker Wall
70	"	Inside Surface of the Bunker Ceiling
71	"	Inside Surface of the Bunker Floor
72	"	Outside Surface of the Bunker Wall
73	"	Approximately 2 ft under the Ground Surface and 4 ft away from the Bunker
74	"	Ground Surface right above the Bunker
75	"	2 ft above the Ground over the Bunker

Table 1 - Continued

Channel No.	Sensor	Location
76	Thermocouple	Wet-bulb Temperature of Outside Air
77	"	Dry-bulb Temperature of Outside Air
78	"	Air Temperature 12 ft above the Ground Surface
79	"	
80	Solar Pyronometer	
81	"	
82	"	
83	Wind Direction	
84	Windspeed	
85	Heatflow Meter	4 in. under Patch No. 1
86	"	4 in. under Patch No. 2
87	"	18 in. under Patch No. 3
88	"	12 in. under Patch No. 3
89	"	4 in. under Patch No. 3
90	"	2 in. under Patch No. 3
91	"	4 in. under Patch No. 4
92	"	4 in. under Patch No. 5
93	Thermocouple	Replacement for Channel 26
94	Rain Gage	Above the Bunker
95	Rain Gage	Above the Bunker

Table 1 - Continued

Channel No.	Sensor	Location
96	Thermocouple	Chassis of the Data Logger
97	Ultra-violet Radiation	Above the Bunker
98		
99		

Table II Wind Direction Conditioner Output

Direction	Output in mV
North	.31
Northwest	.49
West	.73
Southwest	1.03
South	1.18
East	5.54
Northeast	3.51

Table III Potentiometric Check of the Keltec Data Acquisition System

Channel	Patch	Depth in.	Resistance ohms	Rubicon mV	IDVM mV	Rubicon IDVM micro V
1	1	360	190	-2.232	-2.248	16
2	1	240	190	-2.166	-2.176	10
3	1	120	180	-1.870	-1.892	22
4	1	72	180	-1.692	-1.696	4
5	1	48	180	-1.594	-1.598	4
6	1	24	180	-1.527	-1.534	7
7	1	12	190	-1.518	-1.517	-1
8	1	12	190	-1.511	-1.514	3
9	1	4	190	-1.442	-1.425	-17
10	1	2	190	-1.195	-1.235	40
11	1	1	190	-1.229	-1.265	36
12	1	0	190	-1.052	-0.982	70
13	2	360	170	-2.255	-2.261	6
14	2	240	160	-2.179	-2.182	3
15	2	120	155	-1.900	-1.910	10
16	2	72	155	-1.871	-1.877	6
17	2	48	155	-1.867	-1.874	7
18	2	24	155	-1.887	-1.894	7
19	2	12	160	-1.901	-1.901	0

Channel	Patch	Depth in.	Resistance ohms	Rubicon mV	IDVM mV	Rubicon IDVM micro V
20	2	12	155	-1.946	-1.954	8
21	2	4	155	-1.841	-1.836	-5
22	2	2	155	-1.790	-1.791	1
23	2	1	155	-1.758	-1.763	5
24	2	0	165	-1.658	-1.631	-27
25	3	360	250	-2.270	-2.281	11
26	3	240	240	---	---	--
27	3	120	220	-1.810	-1.818	8
28	3	72	230	-1.920	-1.928	8
29	3	48	220	-1.844	-1.851	7
30	3	24	230	-1.884	-1.890	6
31	3	12	220	-1.819	-1.826	7
32	3	12	230	-2.028	-2.040	12
33	3	4	230	-1.653	-1.646	-7
34	3	2	220	-1.593	-1.603	10
35	3	1	220	-1.544	-1.551	7
36	3	0	220	-1.492	-1.179	-213
37	3'	360	260	-2.246	-2.239	-7
38	3'	240	240	-2.215	-2.219	4
39	3'	120	240	-2.028	-2.041	13
40	3'	72	240	-1.926	-1.935	9
41	3'	48	240	---	---	--

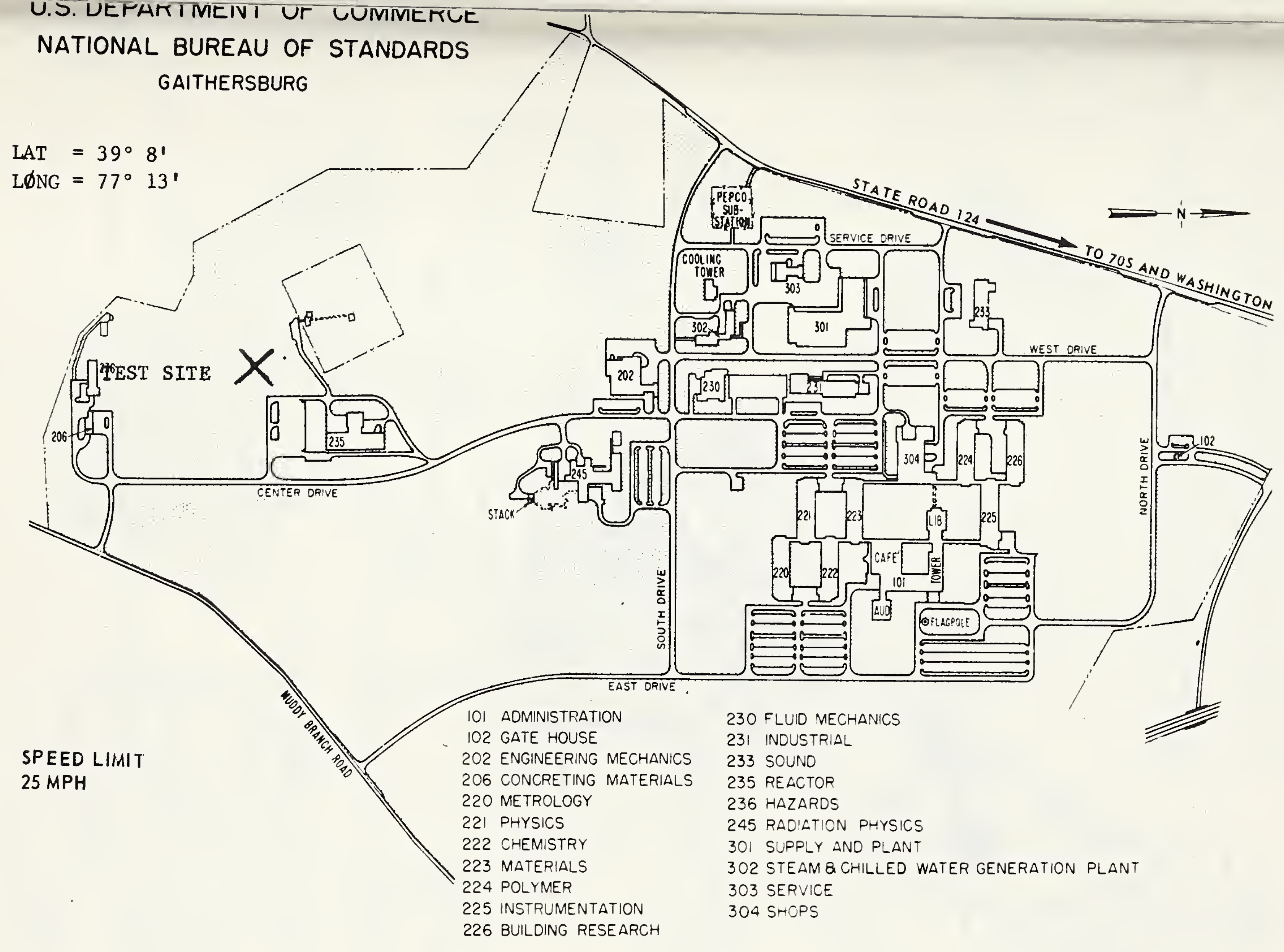
Channel	Patch	Depth in.	Resis-tance ohms	Rubicon mV	IDVM mV	Rubicon IDVM micro V
42	3'	24	240	-1.843	-1.855	12
43	3'	12	240	-1.818	-1.823	5
44	4'	360	210	-2.262	-2.269	7
45	4'	240	210	-2.259	-2.266	7
46	4	120	200	-2.129	-2.137	8
47	4	72	200	-2.023	-2.030	7
48	4	48	200	-1.962	-1.70	8
49	4	24	200	-1.925	-1.931	6
50	4	12	200	-1.913	-1.919	6
51	4	12	200	-1.901	-1.904	3
52	4	4	205	-1.823	-1.834	11
53	4	2	200	-1.799	-1.801	2
54	4	1	200	-1.767	-1.768	1
55	4	0	200	-1.644	-1.486	-178
56	5	360	300	-2.222	-2.230	8
57	5	240	300	-2.218	-2.233	5
58	5	120	300	-1.892	-1.898	6
59	5	72	300	---	---	--
60	5	48	300	-1.919	-1.928	9
61	5	24	280	-1.899	-1.902	3
62	5	12	300	-1.888	-1.898	10
63	5	12	300	-2.072	-2.078	6
64	5	4	290	-1.837	-1.844	7

Channel	Patch	Depth in.	Resistance ohms	Rubicon mV	IDVM mV	Rubicon IDVM micro V
65	5	2	290	-1.822	-1.833	11
66	5	1	300	-1.840	-1.858	18
67	5	0	300	-1.451	-1.141	-10
68	Zone Box			+1.170	1.168	2
69	Bunker Wall					
70	" Ceiling			-0.085	-0.089	4
71	" Floor			-0.072	-0.076	4
72	" Soil			-0.109	-0.112	3
73	Soil			-0.256	-0.260	4
74	Earth Surface			+0.073	+0.077	4
75	2' above Ground			+1.166	+1.221	-55
76	DB			+1.120	+1.160	-40
77	WB			+1.113	+1.184	-71
78	12' above Ground			+1.151	+1.215	-64
79						
80	Solar			+1.368	+2.353	-985
81						
82						
83	Wind air					
84	Wind Speed			+0.038	+0.029	9
85	Heat Flux			-6.800	-6.197	-603
86	Heat Flux			-3.885	-3.701	-184
87	Heat Flux			+0.764		

Channel	Patch	Depth in.	Resistance ohms	Rubicon mV	IDVM mV	Rubicon IDVM micro V
88	Heat Flux			+0.377	0.537	-160
89	Heat Flux					
90	Heat Flux			+8.334	10.324	-1990
91	Heat Flux			-3.005	2.909	-96
92	Heat Flux			-3.472	-3.340	-132
93				-2.233	-2.227	-6
94	Rain Gage			-0.063	-0.062	-1
95	Rain Gage			-0.002		
96	Bunker Air			+2.756	2.751	5
97						
98						
99						

Table IV Summary of Temperature Measurement Errors

e_{TH}	Thermoelectric error	5 microvolts
e_{Ga}	Galvanic error	2 microvolts
e_{τ}	Triboelectric error	1 microvolt
e_D	Drift or stability error	10 microvolts
e_{NM}	Normal mode error	7 microvolts
e_{CM}	Common mode error	
e_K	Stem conduction error	2 microvolts
e_{Re}	Reference junction error (0.5 °F)	10 microvolts
e_{Tc}	Thermocouple wire calibration (0.75 °F)	5 microvolts
	Total	42 microvolts



FORM NBS-3? (10-68)

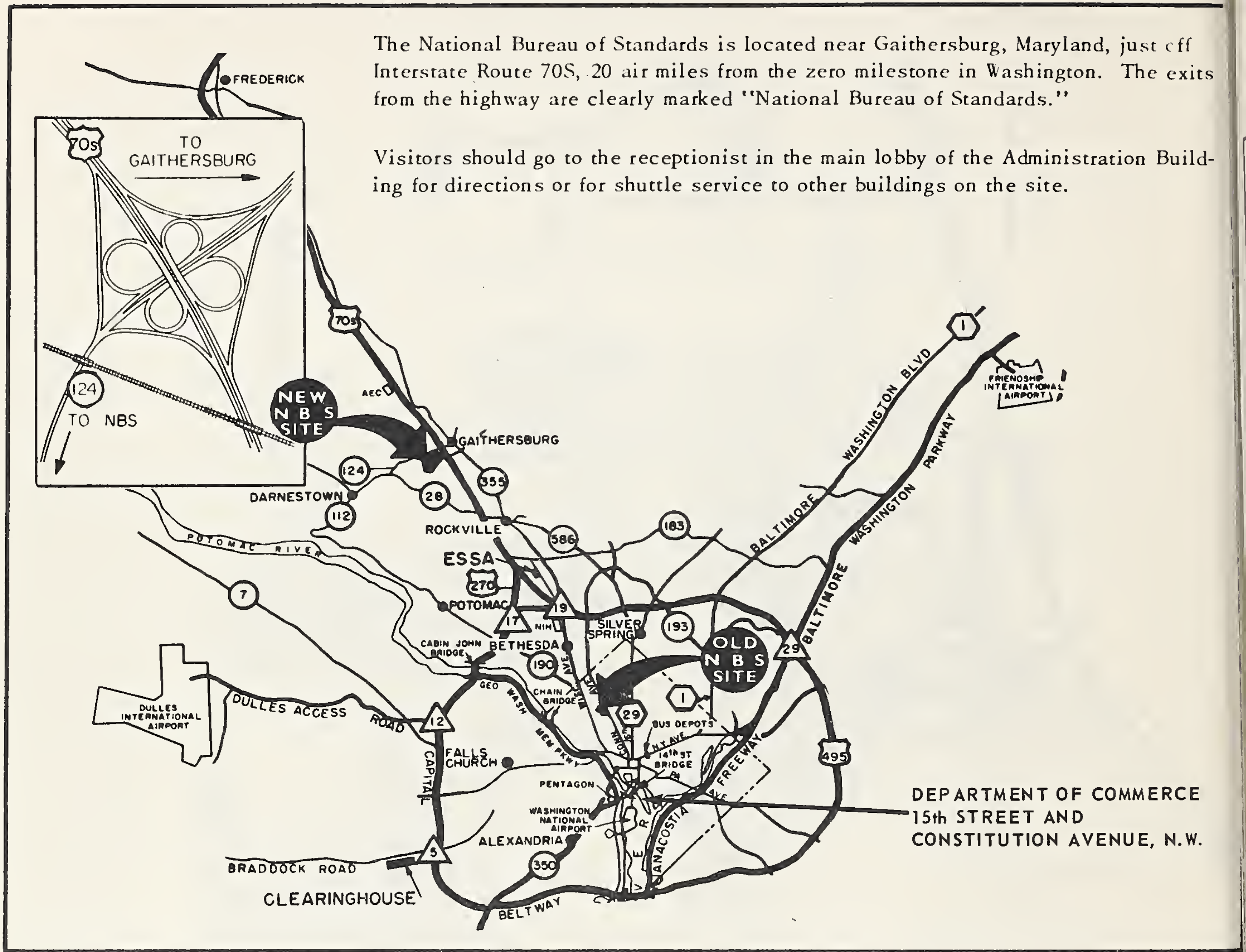
Figure 1 Location of the Earth Temperature Site on the Grounds of the National Bureau of Standards, Gaithersburg, Maryland

USCOMM-DC

HOW TO GET TO NBS

The National Bureau of Standards is located near Gaithersburg, Maryland, just off Interstate Route 70S, 20 air miles from the zero milestone in Washington. The exits from the highway are clearly marked "National Bureau of Standards."

Visitors should go to the receptionist in the main lobby of the Administration Building for directions or for shuttle service to other buildings on the site.



DRIVING INSTRUCTIONS:

From Downtown Washington –

Connecticut Avenue to the Beltway and Route 70S North; **or**
River Road (Route 190) to the Beltway, **or**
George Washington Memorial Parkway to the Beltway
Beltway to Route 270 and Route 70S North

From Dulles Airport –

Dulles Access Highway to Beltway.
Beltway to Route 270 and Route 70S North

From National Airport –

George Washington Memorial Parkway to the Beltway
Beltway to Route 270 and Route 70S North

From Friendship Airport –

Washington - Baltimore Parkway to Beltway
Beltway to Route 70S North

Note: The George Washington Memorial Parkway is on the Virginia side of the Potomac.

OTHER TRANSPORTATION:

There is no satisfactory public transportation from the Washington area to the Bureau at Gaithersburg. However the Bureau provides a shuttle service for official visitors and staff leaving the Department of Commerce (15th Street entrance nearest Constitution Avenue) every hour 8:10 a.m. to 4:10 p.m. Travel time is approximately 40 minutes.

Return service on the same schedule leaves from the front of the Administration Building.

Please make arrangements in advance for a seat on the shuttle. Call 921-2615.

USCOMM-DC 22099-P68

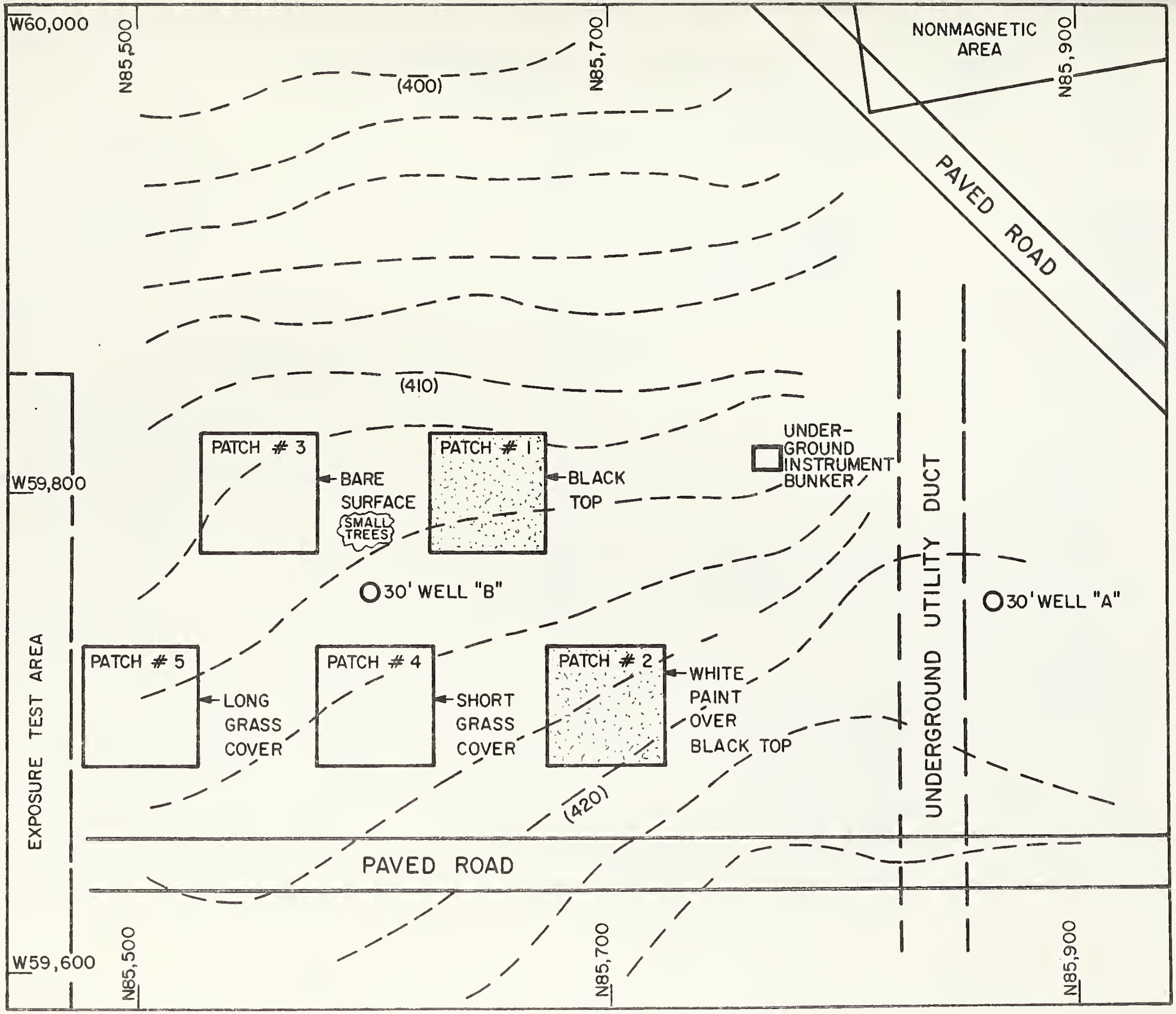


Figure 2 Detailed Topographic Map of the Earth Temperature Site

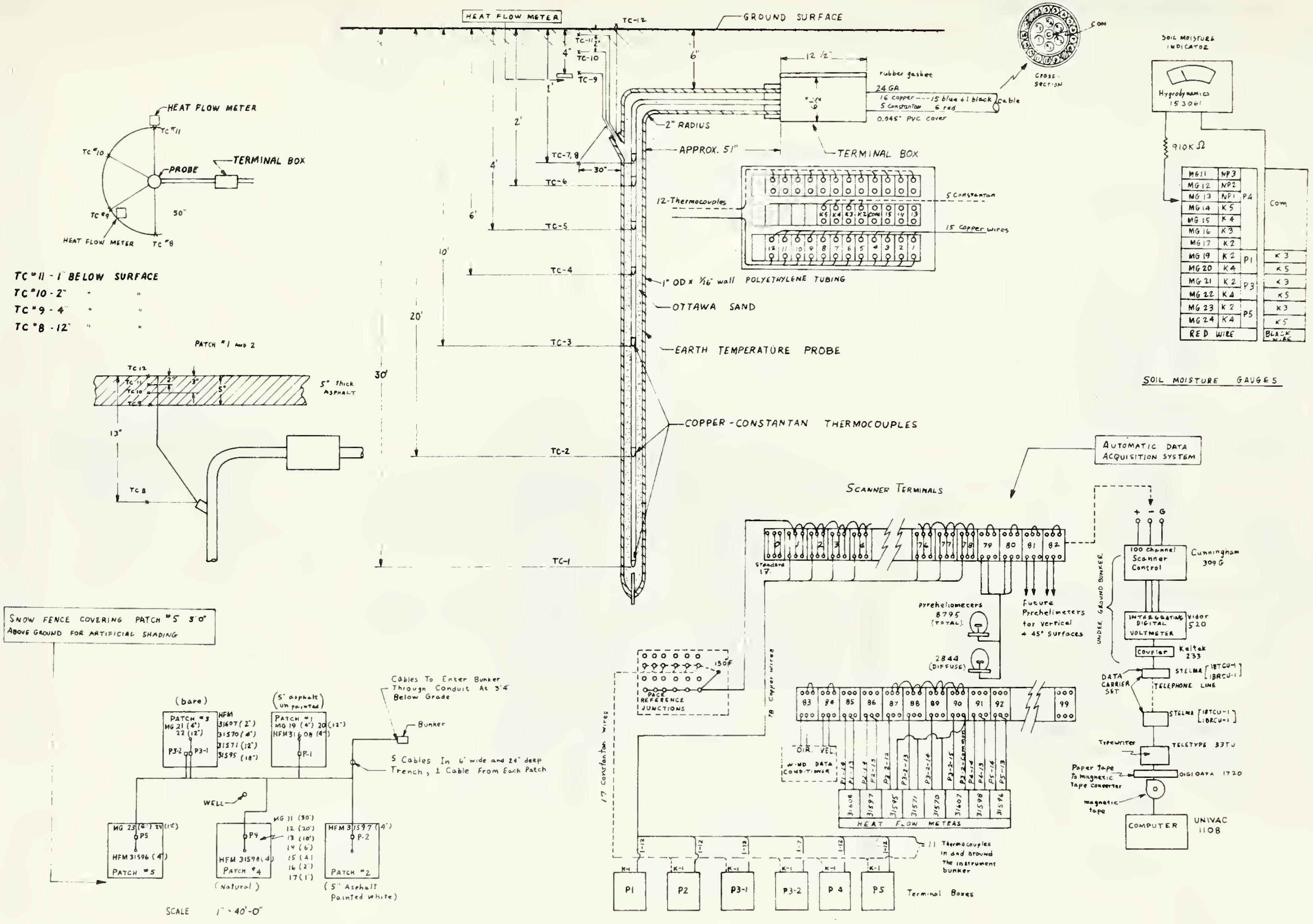
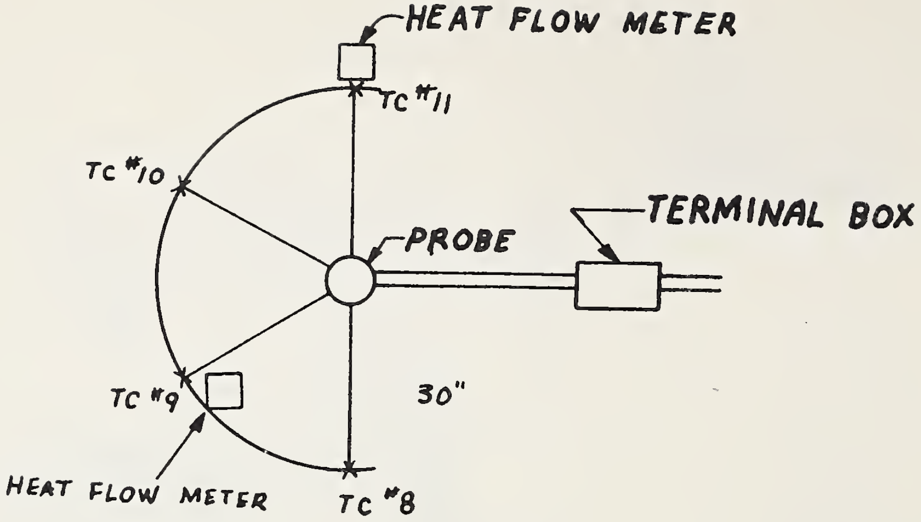


Figure 3 Prototype of the Earth Temperature Probe and Its Underground Installation and Other Related Figures



TC #11 - 1" BELOW SURFACE
TC #10 - 2" " "
TC #9 - 4" " "
TC #8 - 12" " "

PATCH #1 AND 2

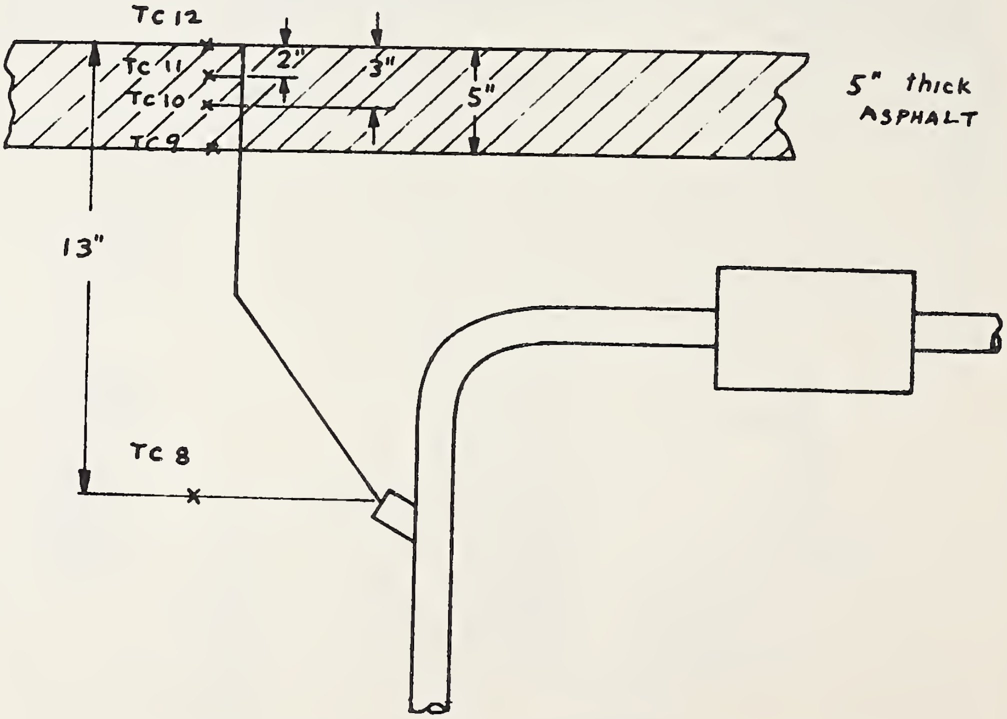


Figure 3A Installation of Thermocouples Near the Ground Surface

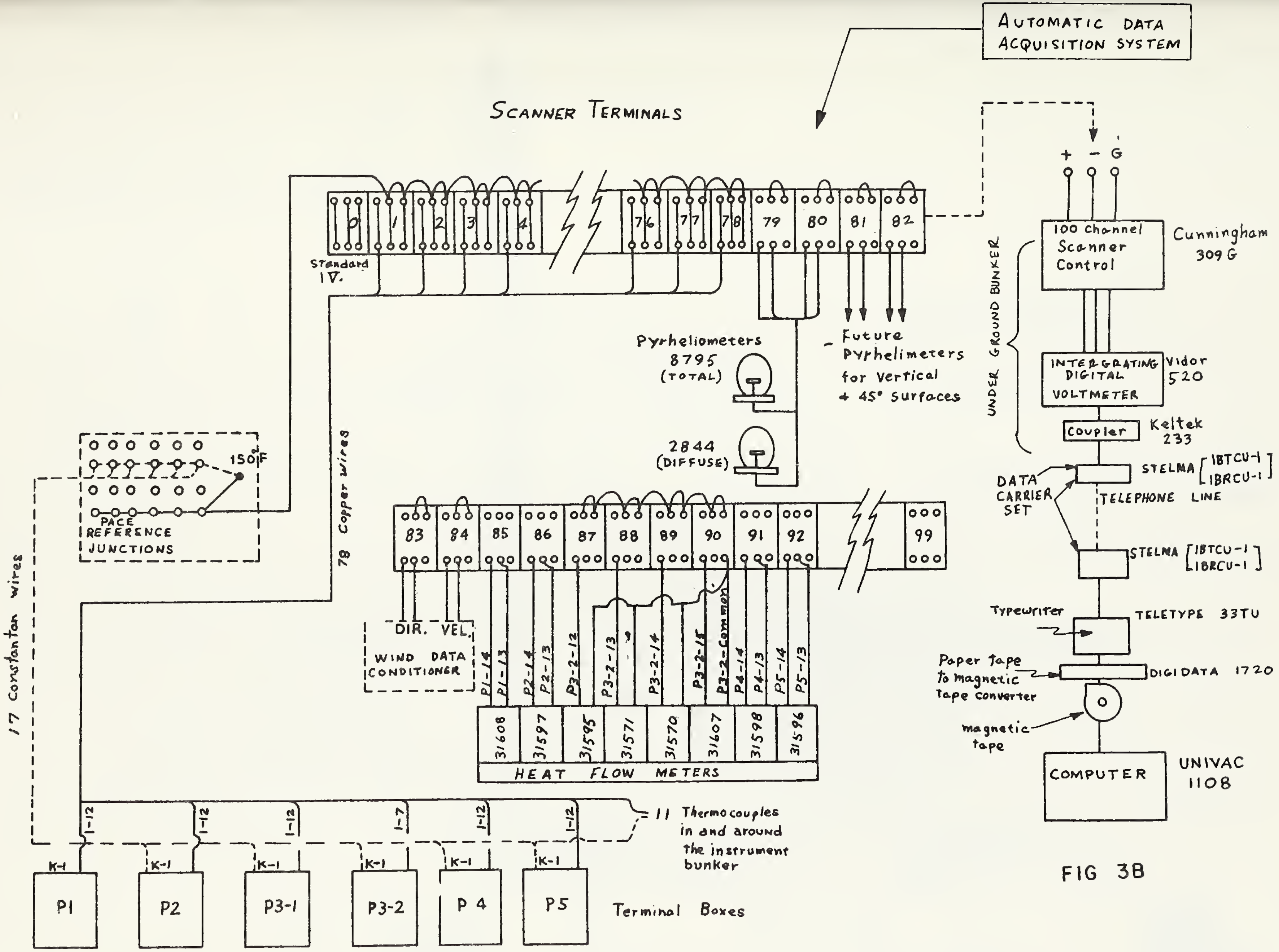


FIG 3B

Figure 3B Connection of Various Transducers to the Scanner Terminals

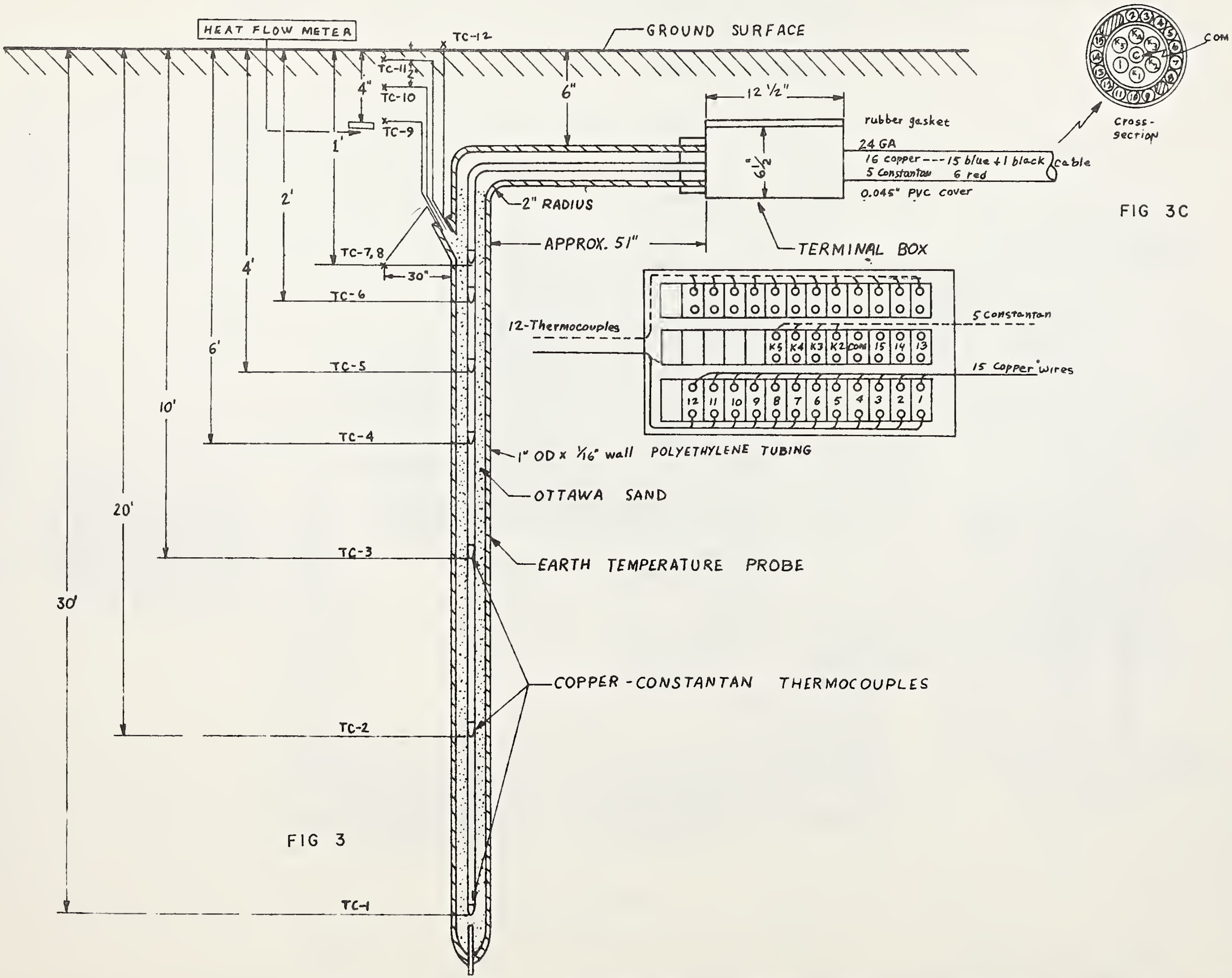


Figure 3C Earth Temperature Probe and Transducer Conduit

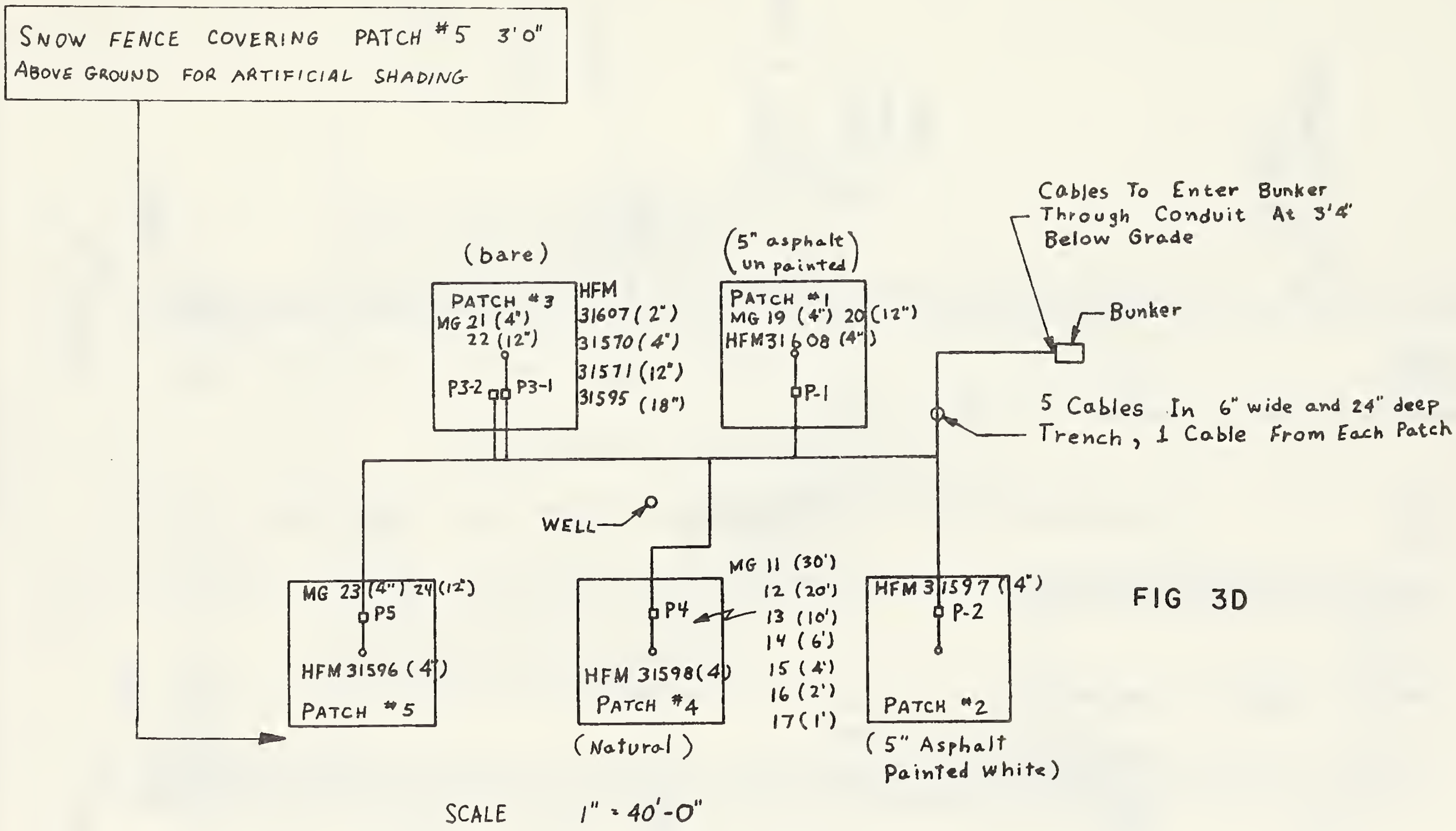


FIG 3D

Figure 3D Assignment of Heat Flow Meters and Moisture Gauges

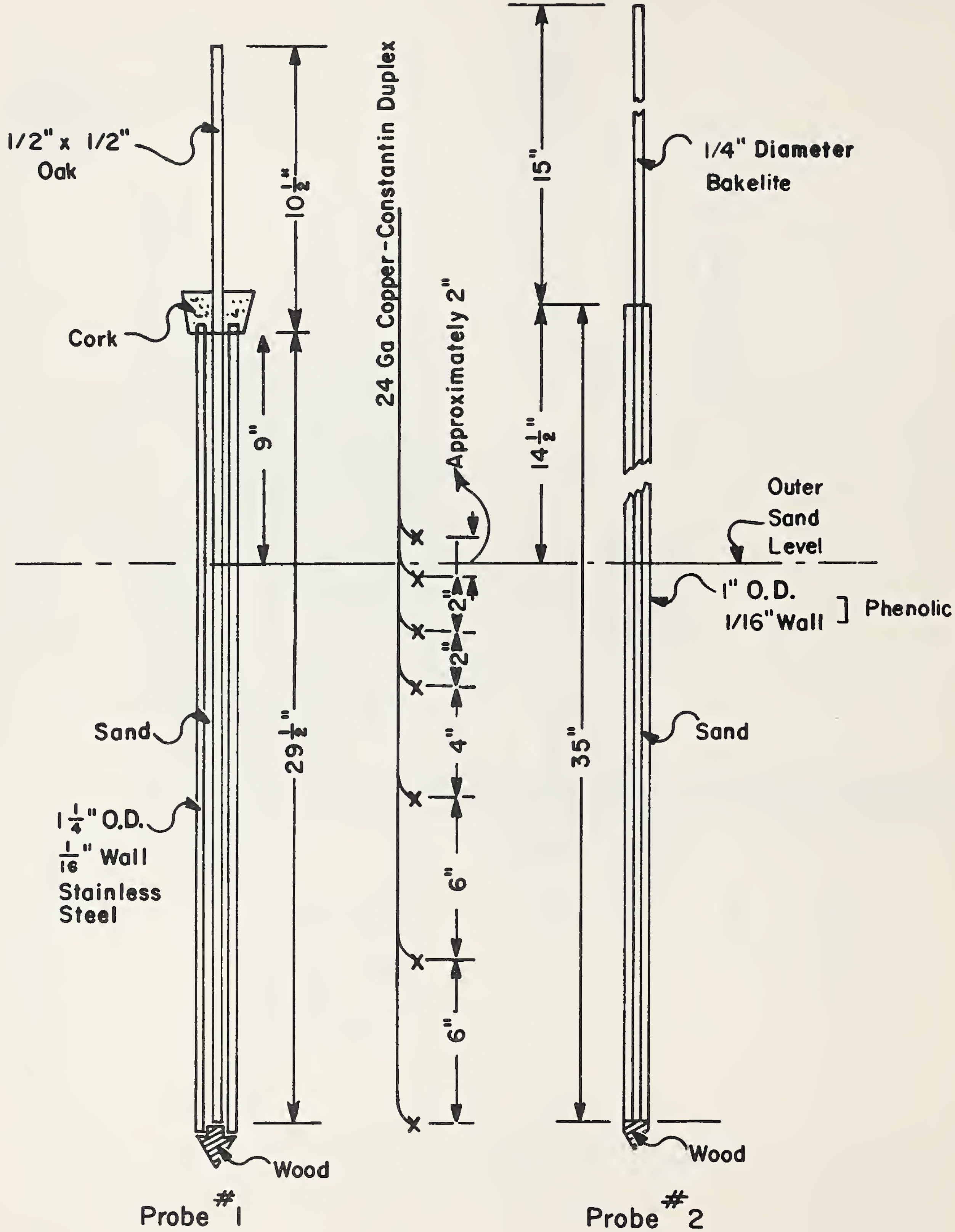


Figure 4 Laboratory Model of a Thermocouple Earth Temperature Probe

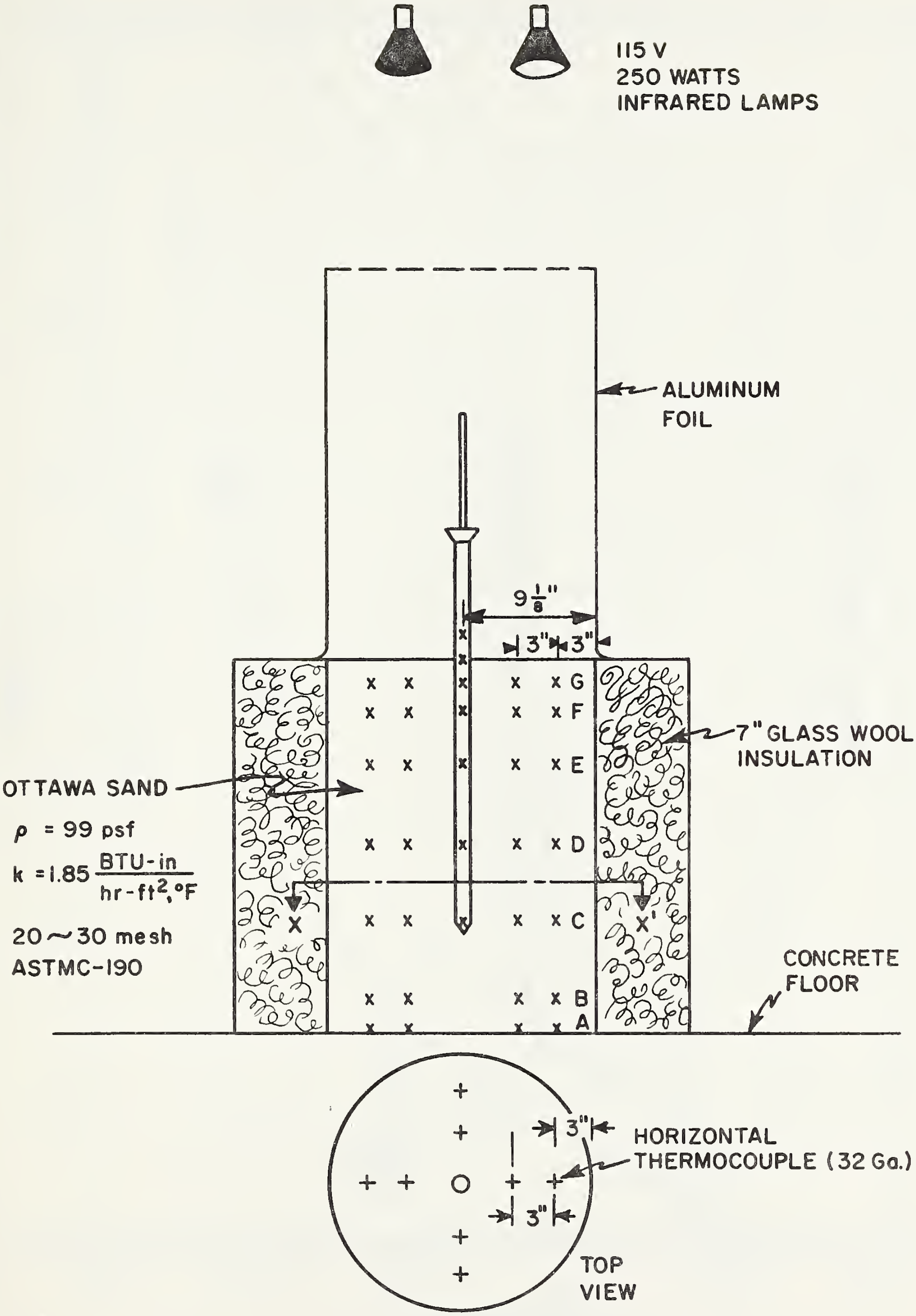


Figure 5 Laboratory Study of the Temperature Probe--Heat Conduction Error Analysis

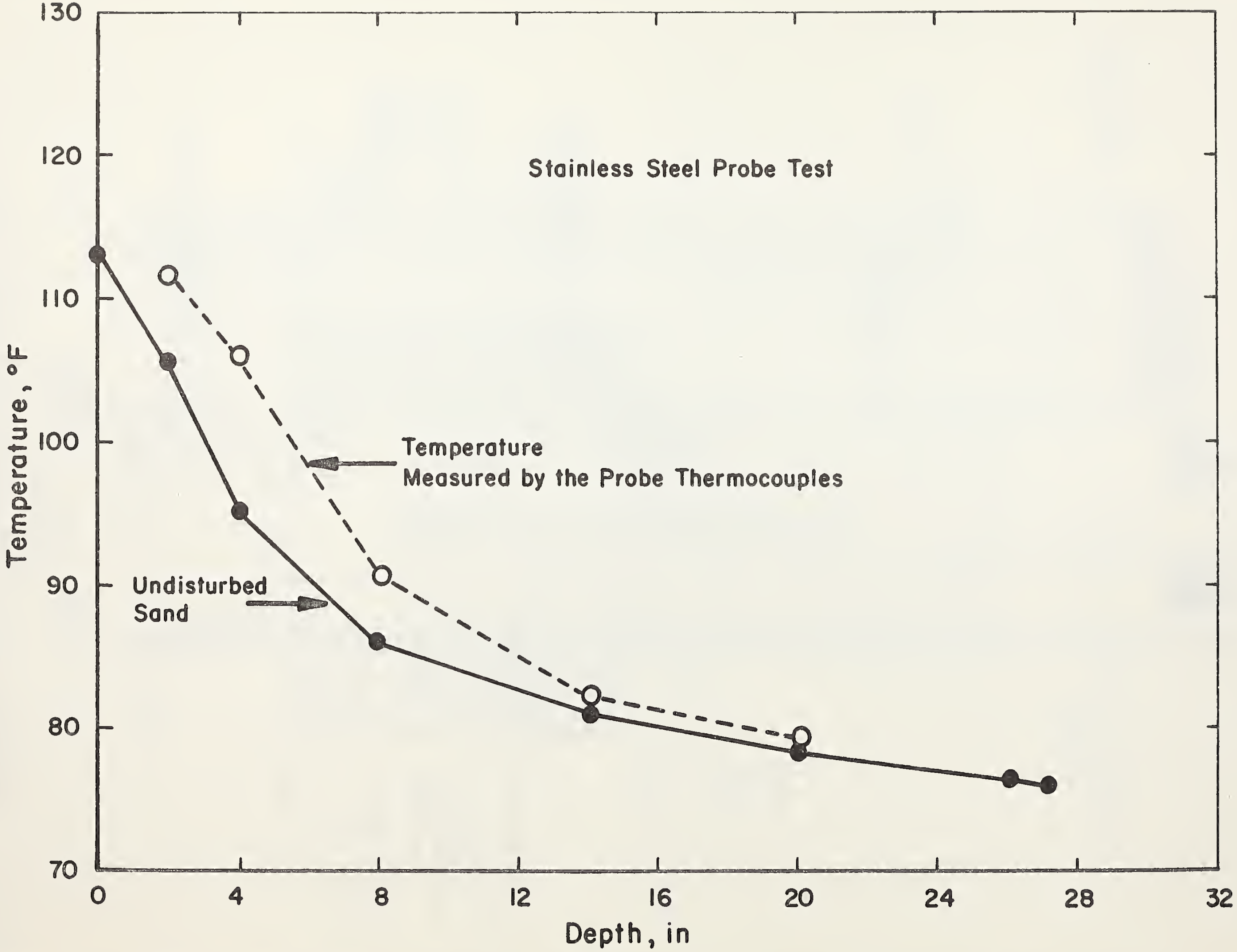


Figure 6 Comparison of Sand Temperature Measured by a Vertical Probe and by Thermocouples Horizontally Installed in the Sand at the Same Depth

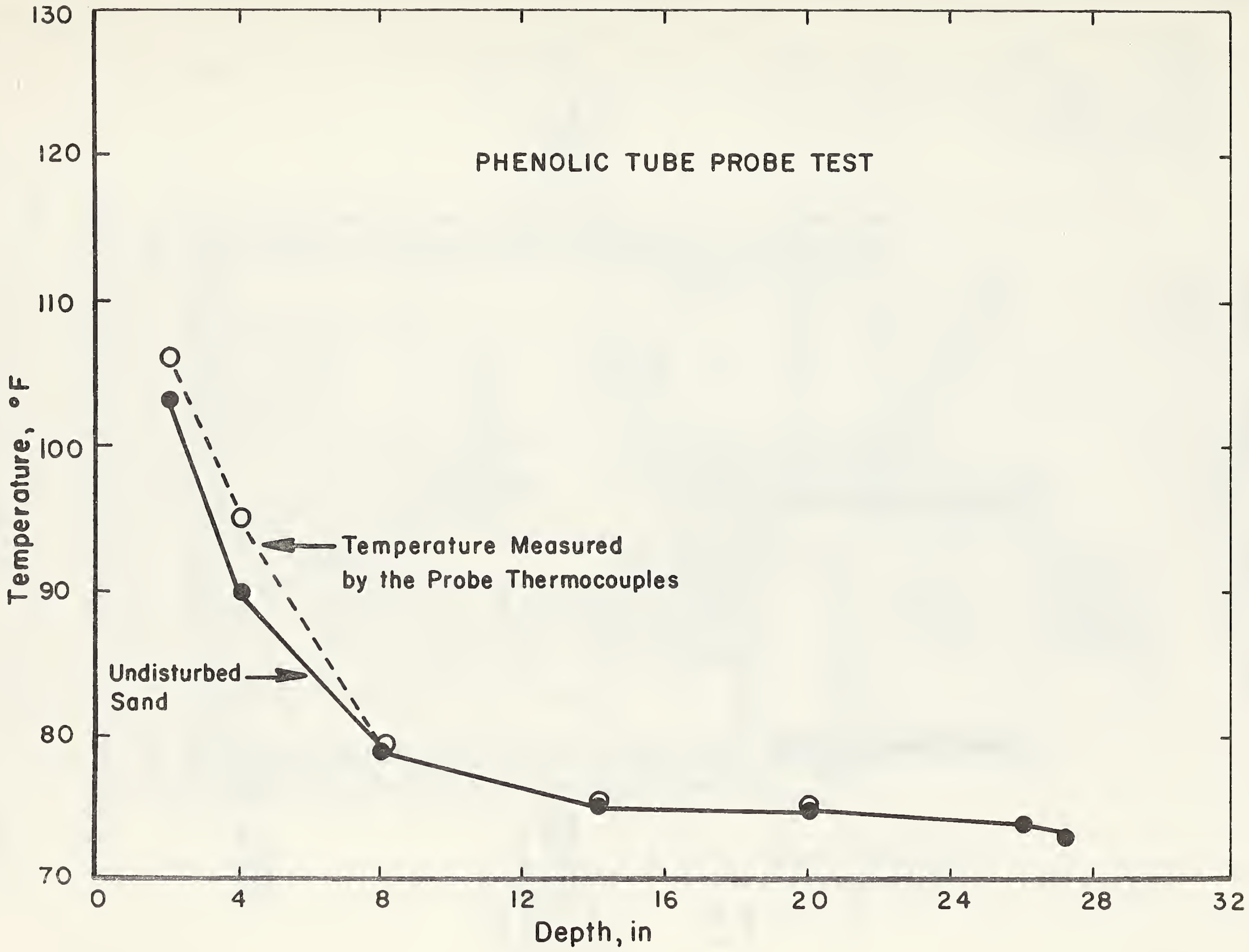
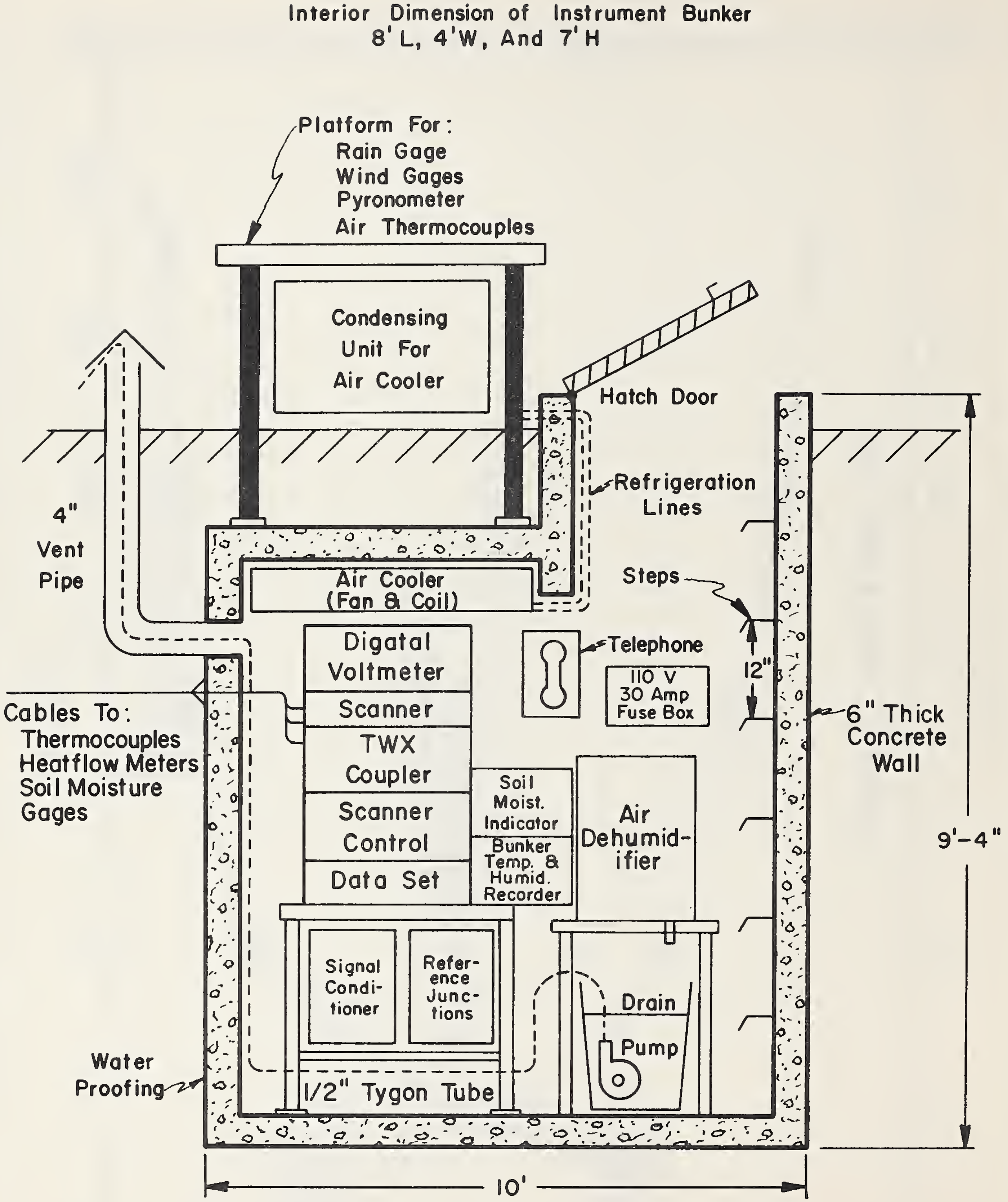
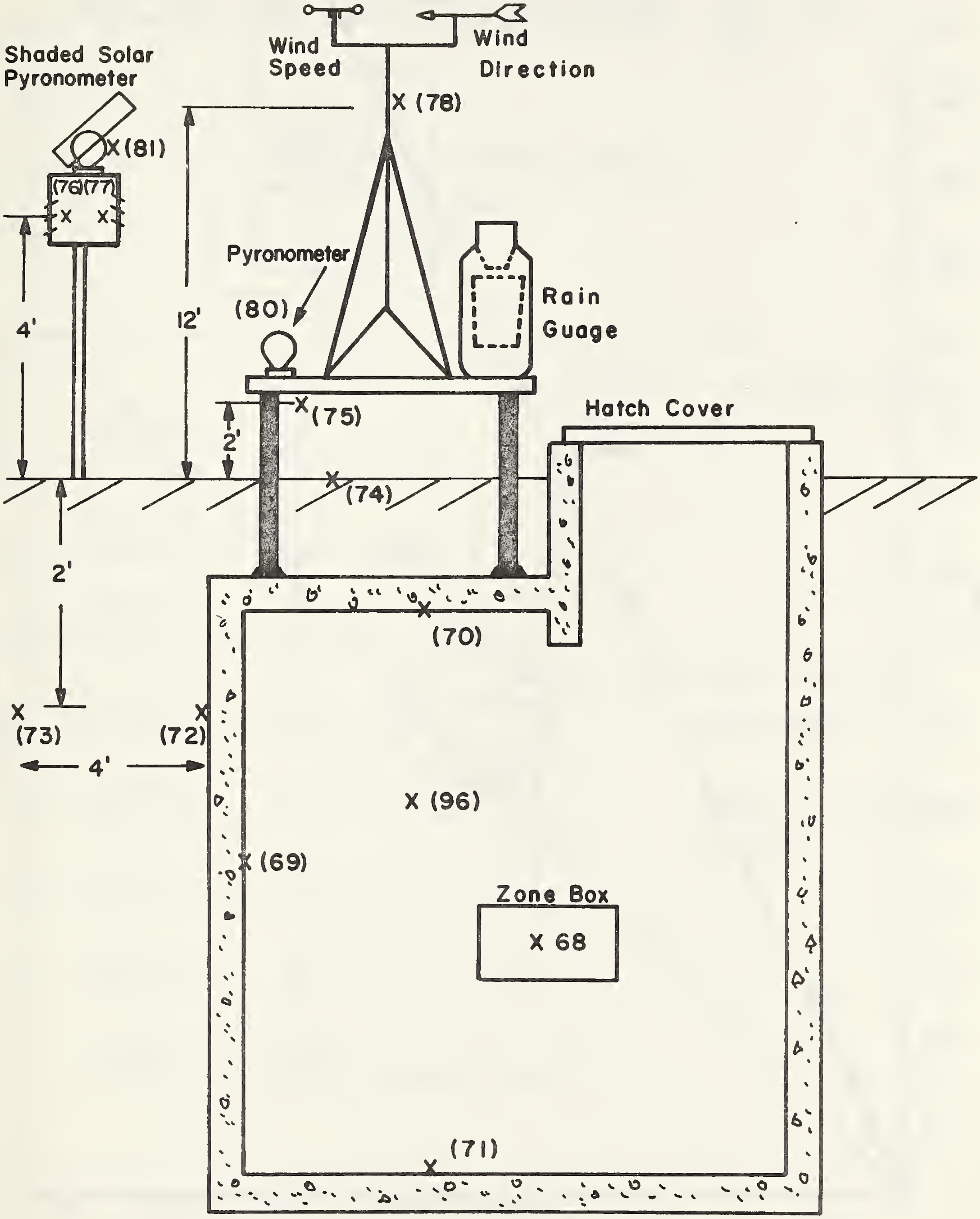


Figure 6A Comparison of Sand Temperature Measured by a Vertical Probe and by Thermocouples Horizontally Installed in the Sand at the Same Depth



FACILITIES IN THE UNDERGROUND INSTRUMENT BUNKER

Figure 7 Underground Instrument Bunker and Its Facilities



X Thermocouple Locations in and around Instrument Bunker

Figure 8 Thermocouple Installation In and Around the Bunker

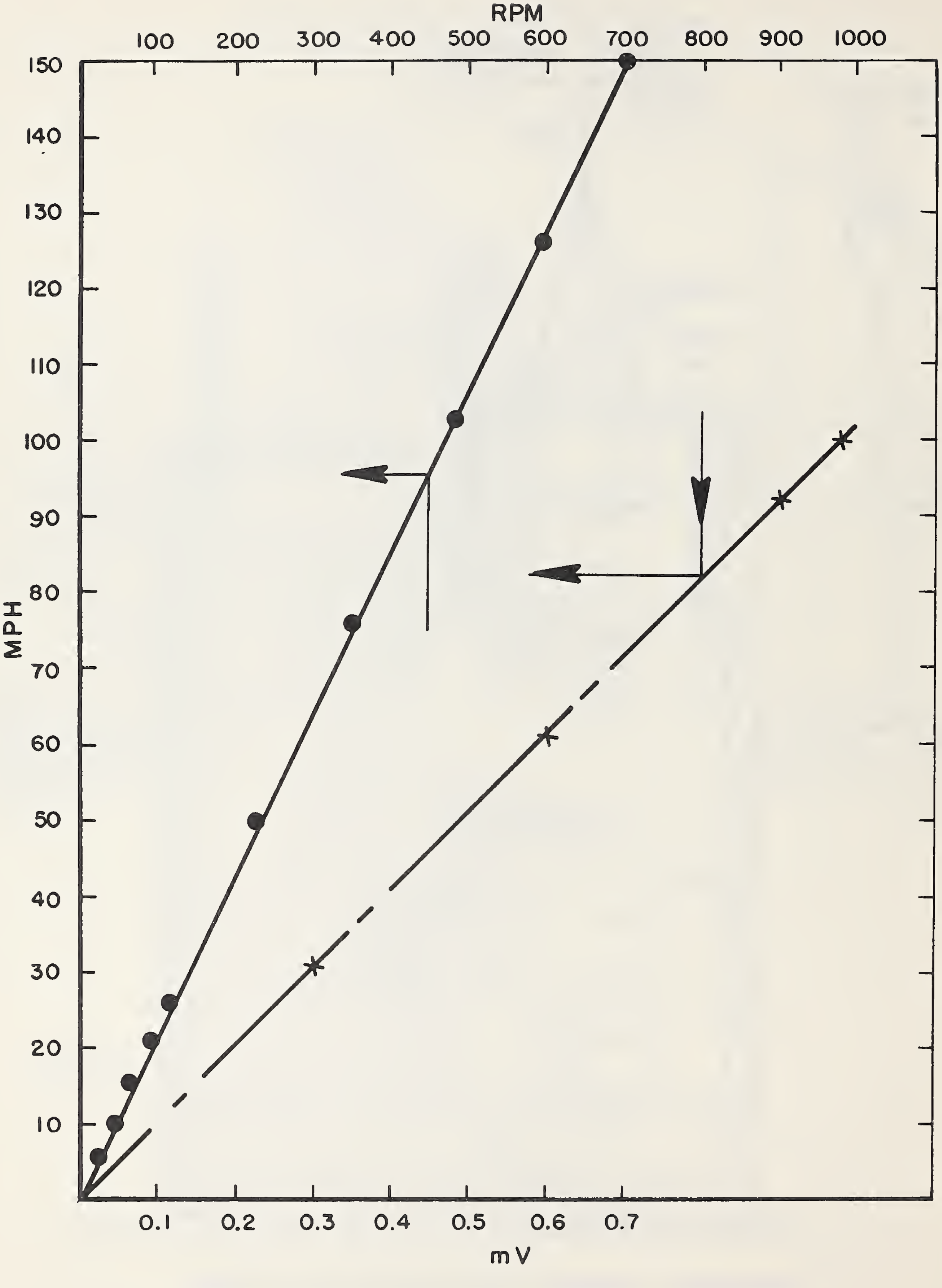


Figure 9 Calibration Curve for the Wind Velocity Gauge

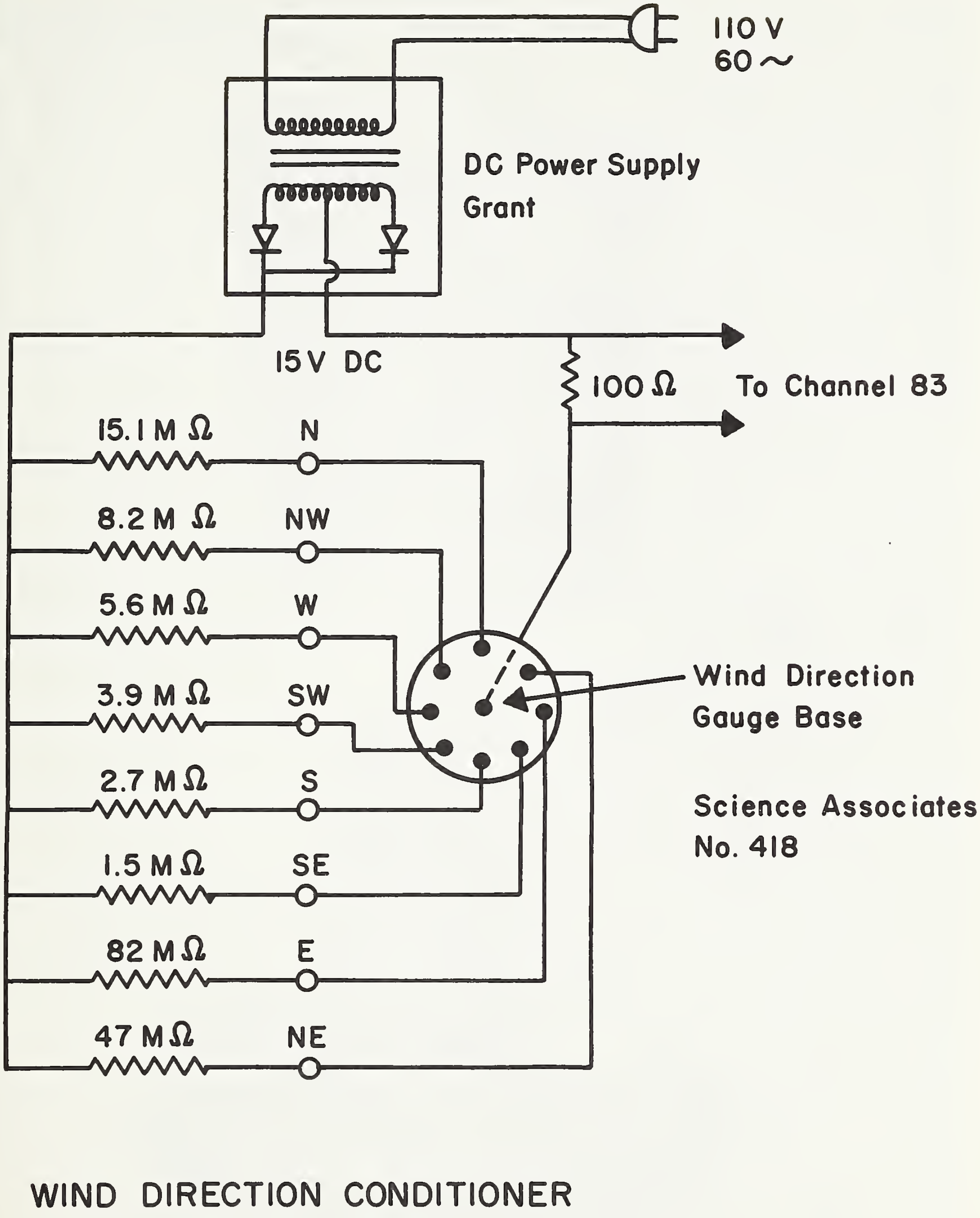


Figure 10 Wind Direction Signal Conditioner Circuit

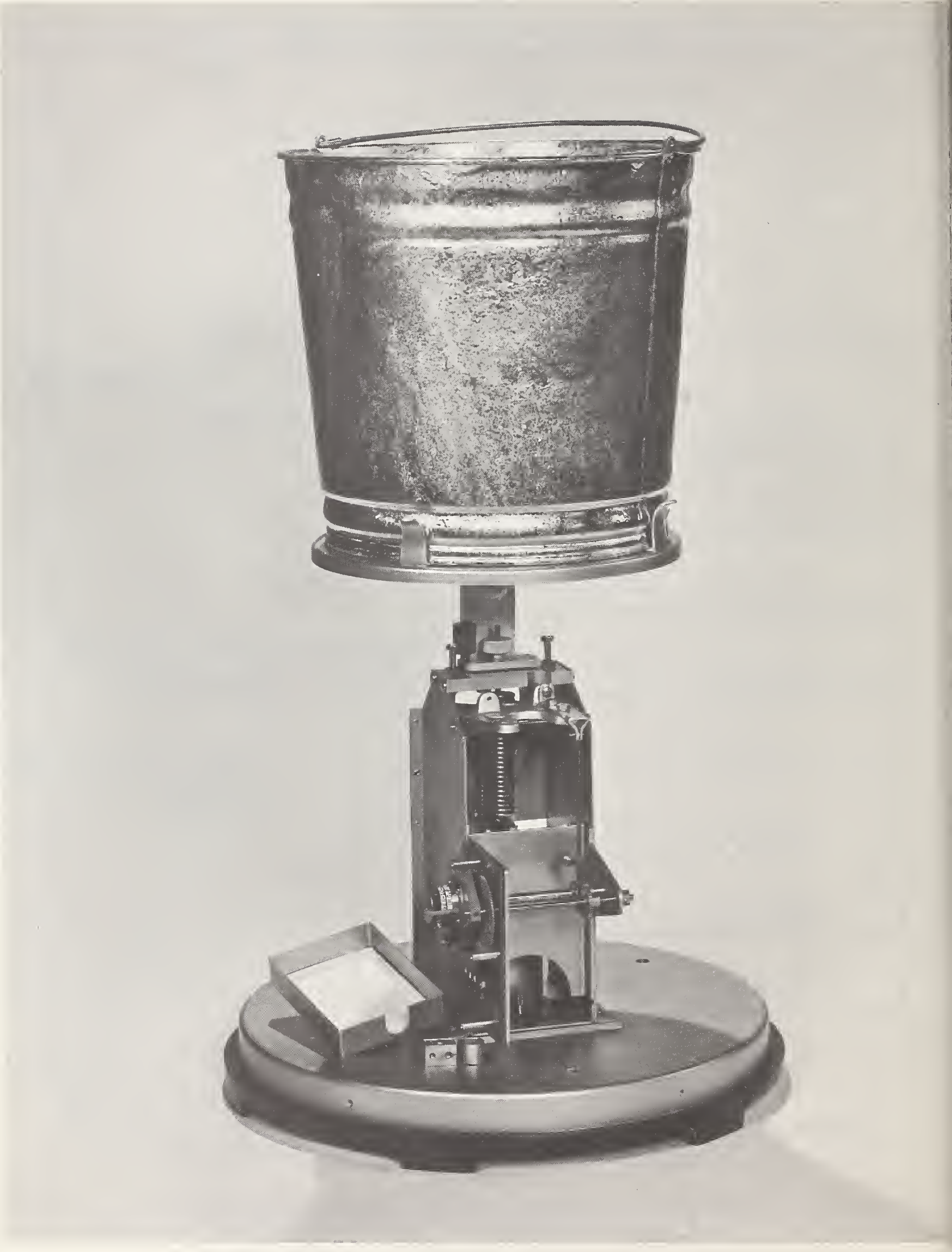


Figure 11 Rain Gauge

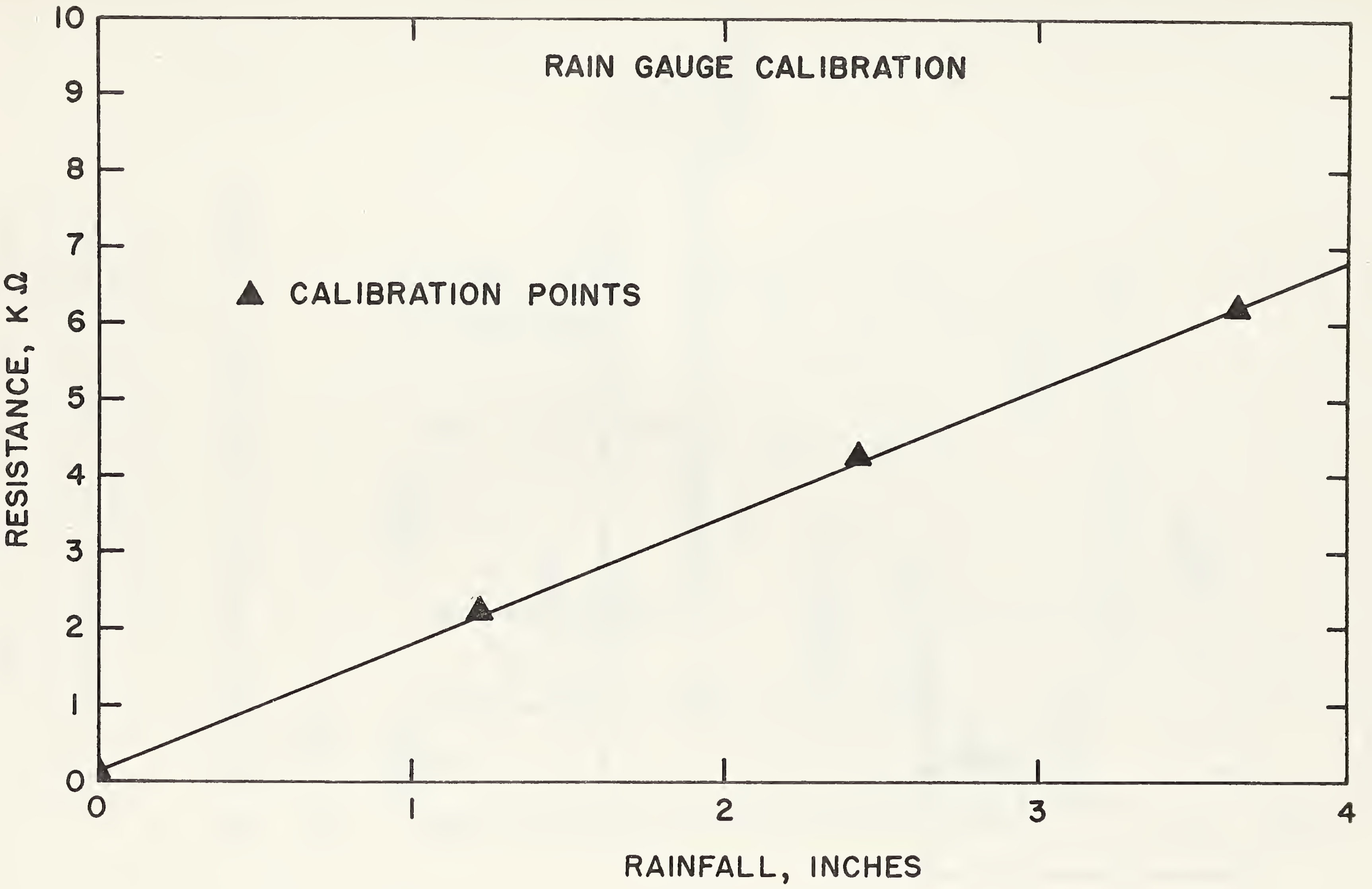
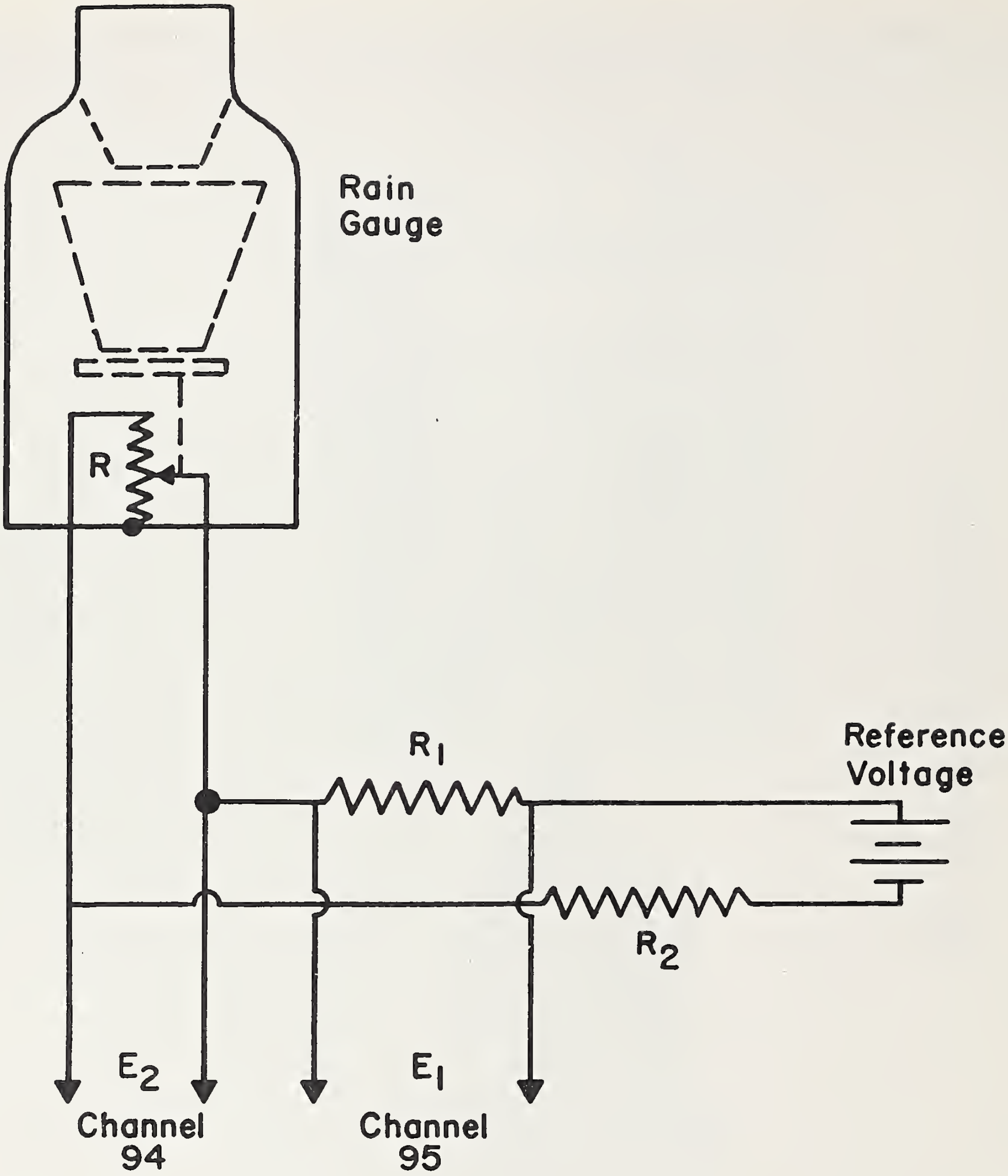


Figure 12 Rain Gauge Calibration



$$R = \frac{E_2}{E_1} R_1$$

R: A Linear Function of RAIN FALL (Inches)

RAIN GAUGE SIGNAL CONDITIONER

Figure 13 Rain Gauge Signal Conditioner

TYPICAL CONSTRUCTION DETAILS

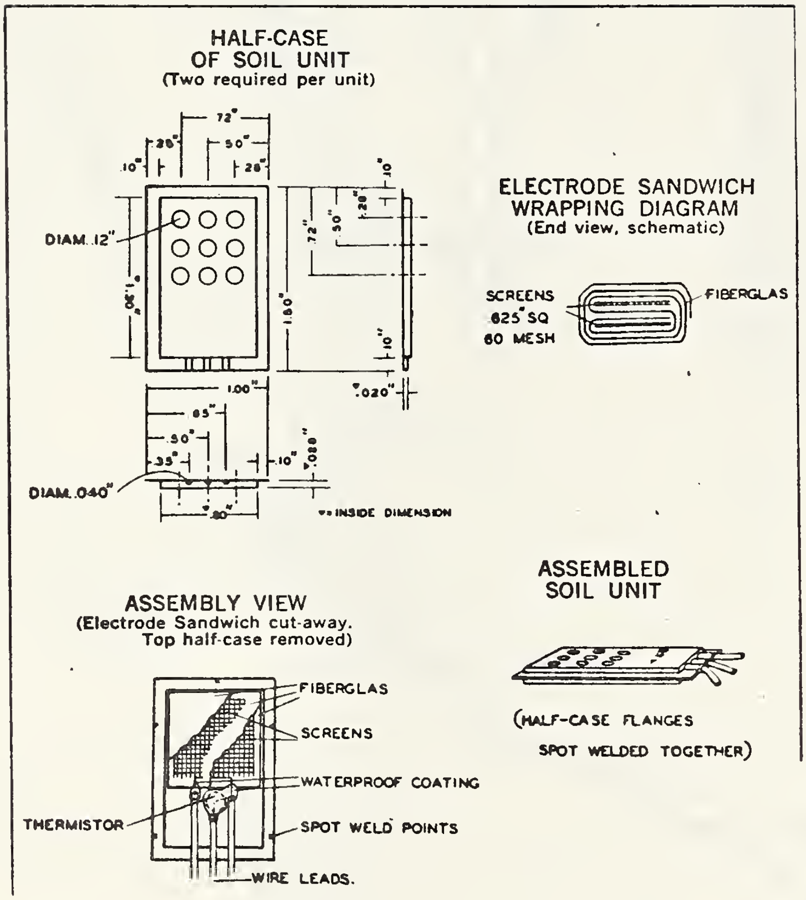


Figure 14 Soil Moisture Gauge

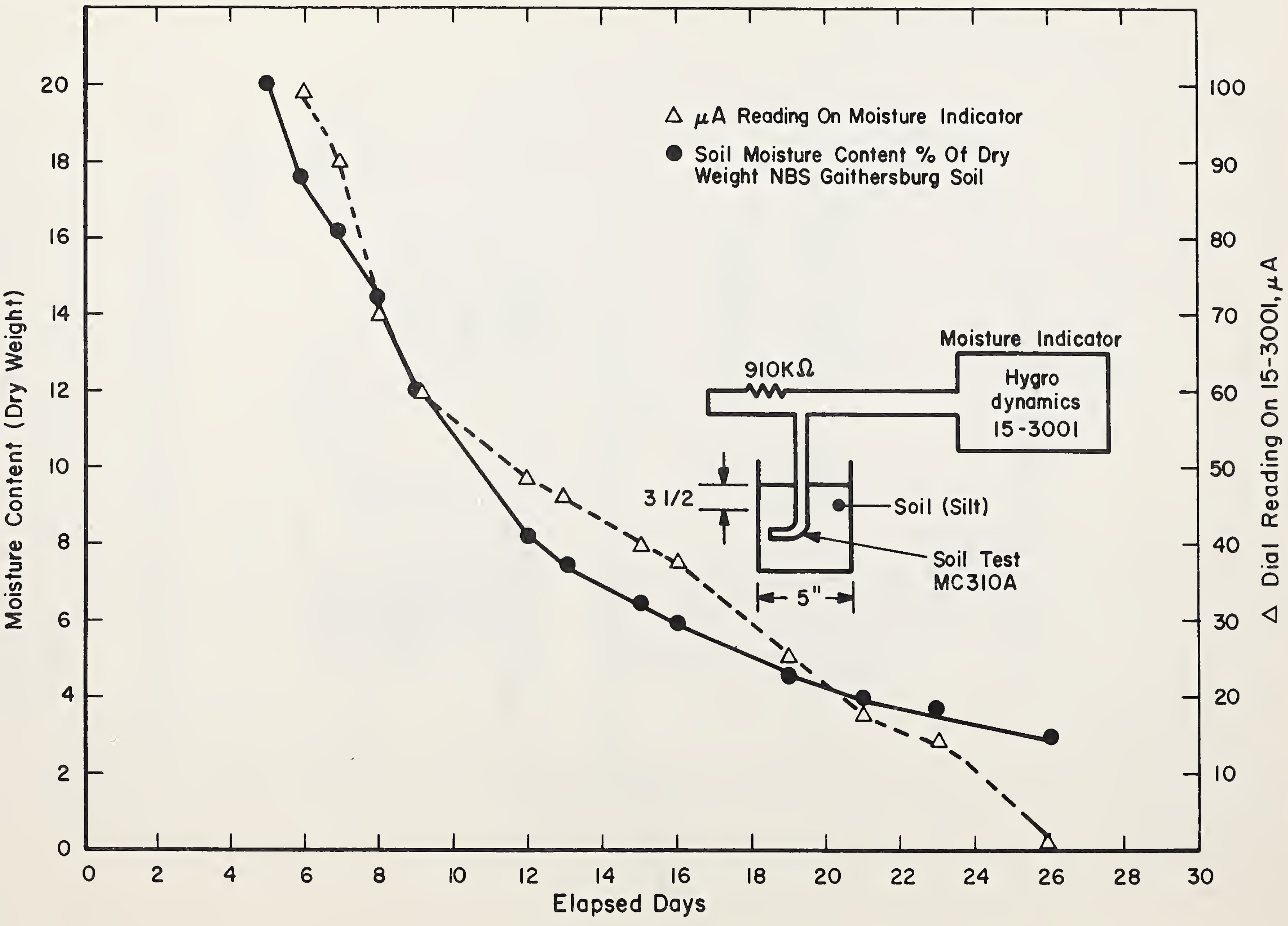
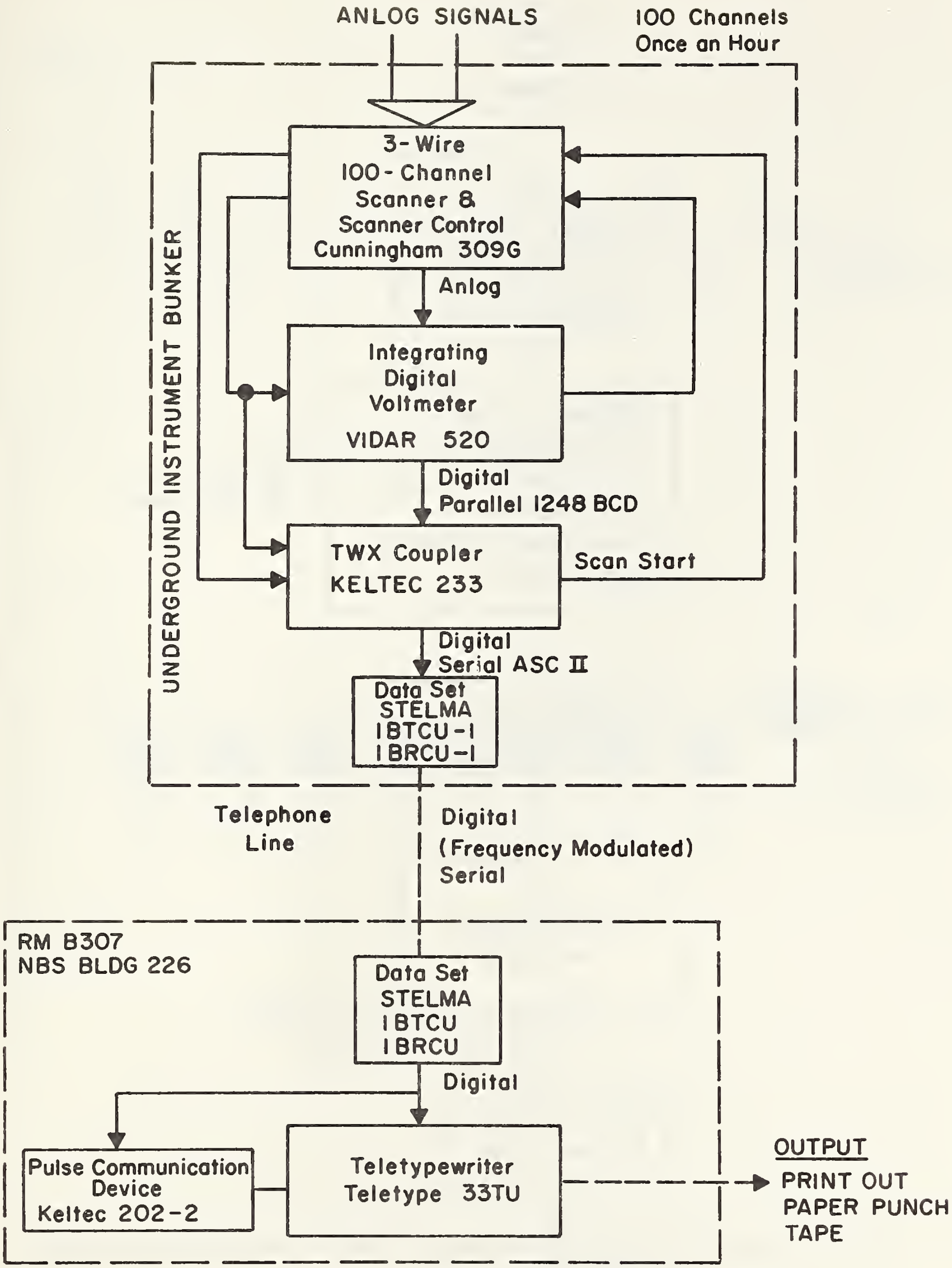
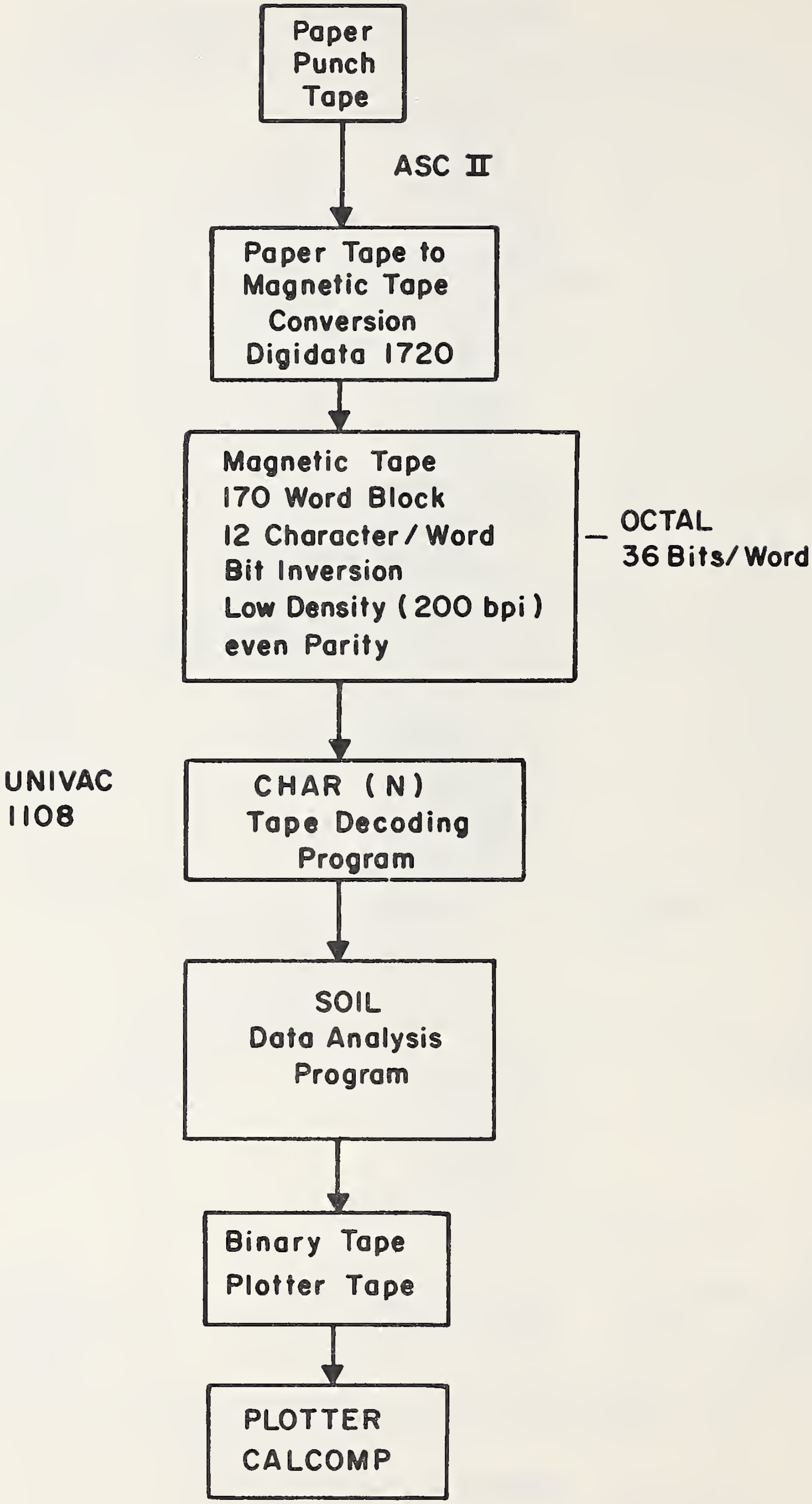


Figure 15 Laboratory Calibration Results of a Soil Moisture Gauge

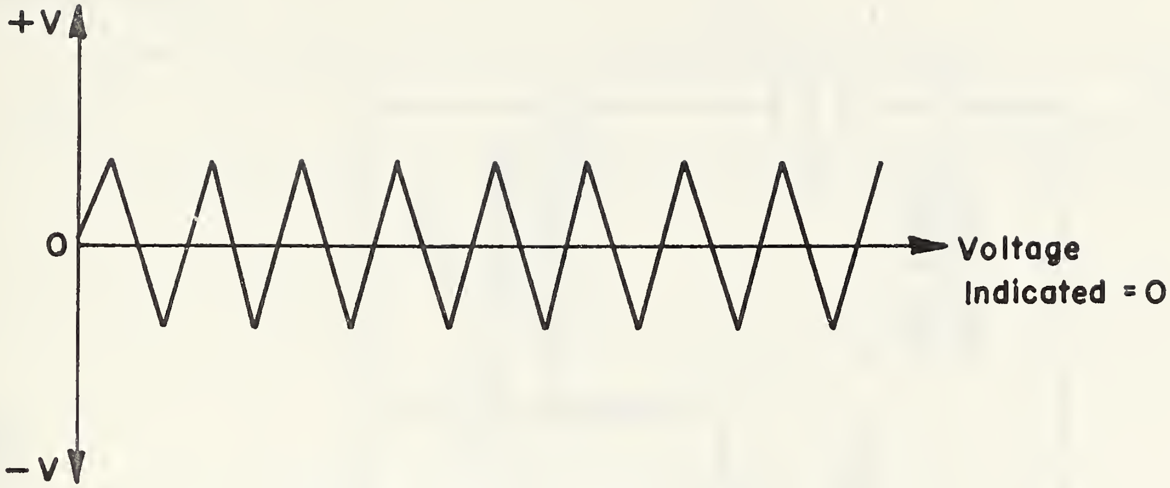


KELTEC CP-2330 SYSTEM

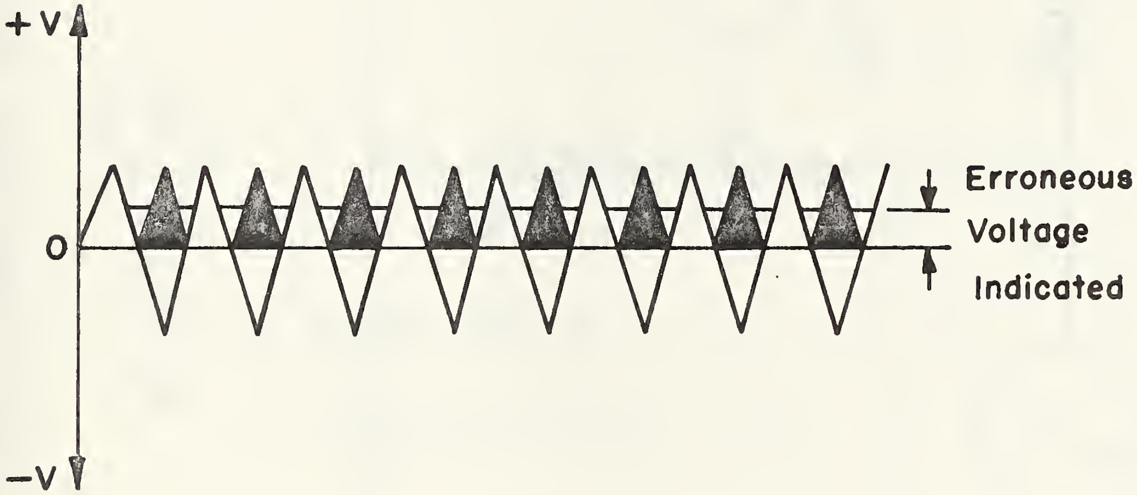
Figure 16 Overall Flow Diagram for the Data Acquisition System



Continuation of Figure 16



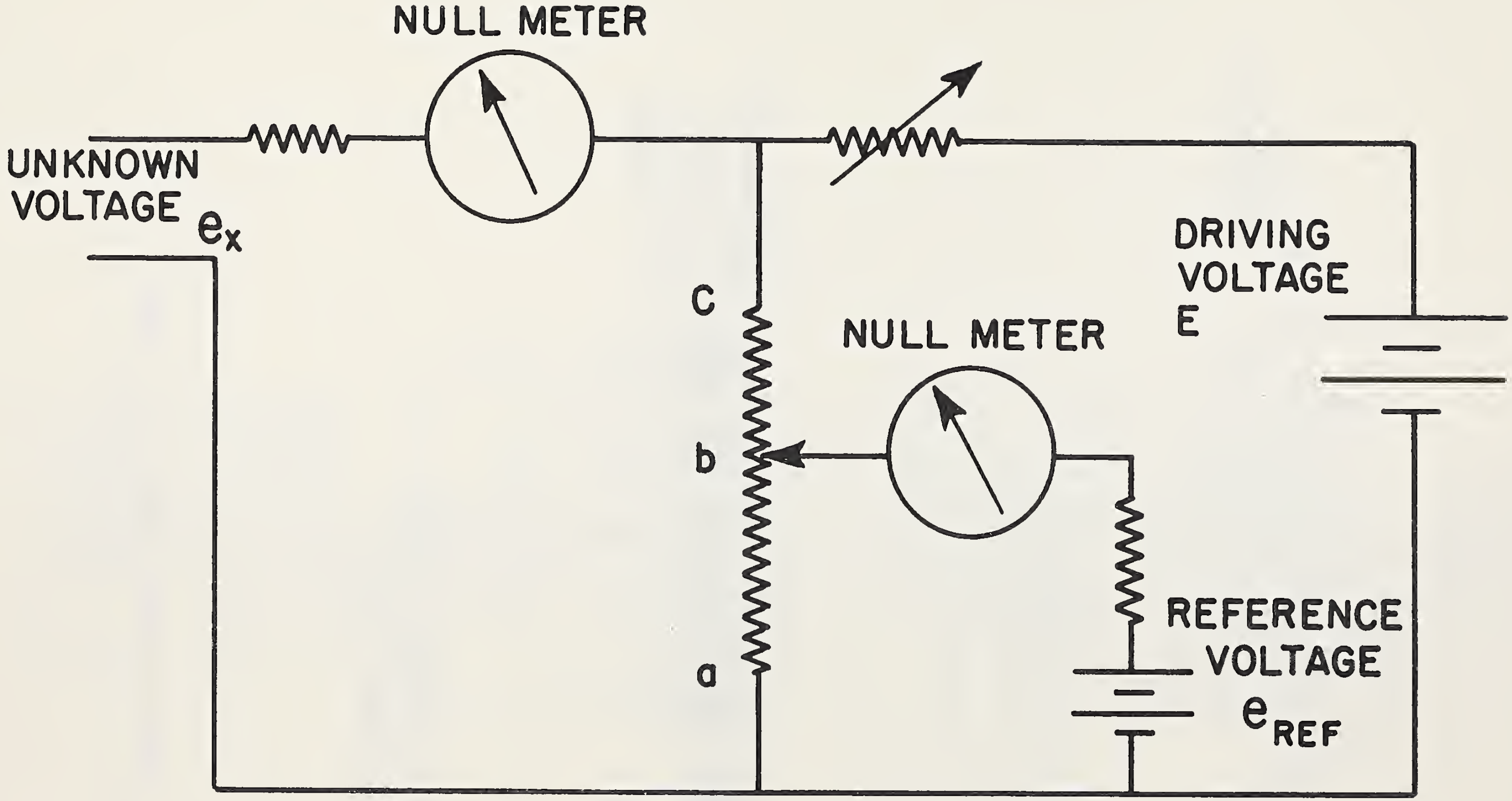
With up-down counter



Without up-down counter
(rectifying effect)

Effect of up-down counter on low-level D.C. signal

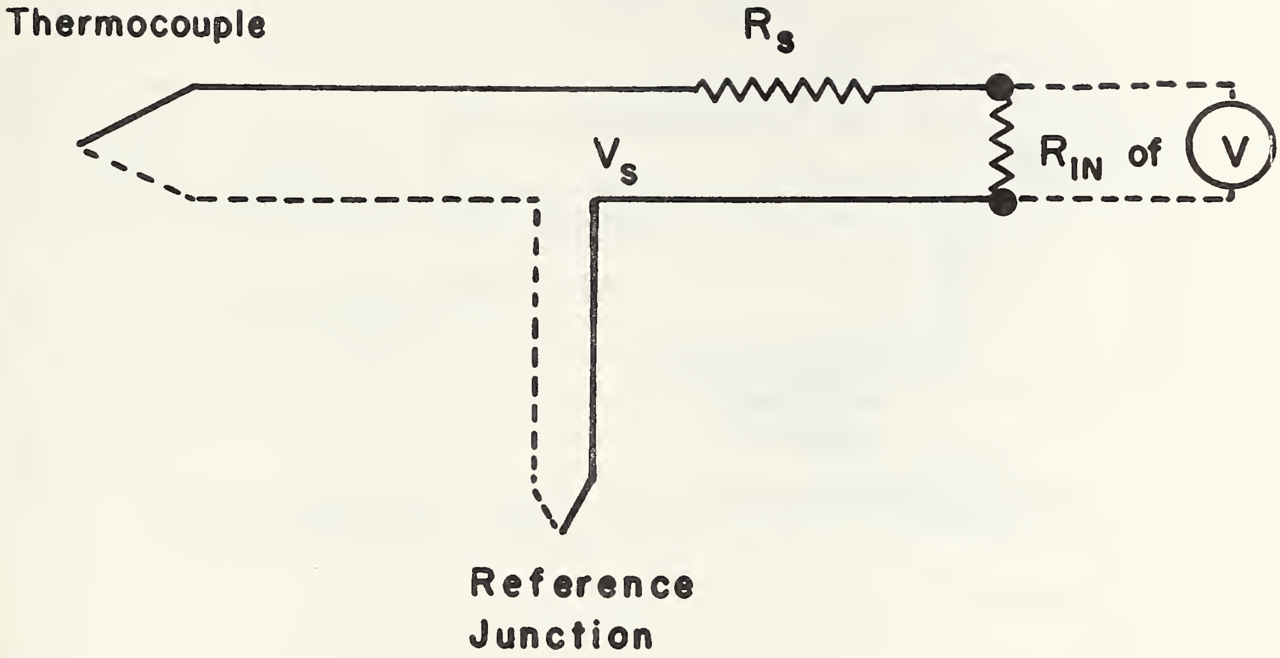
Figure 17 AC Noise Crossing of Zero Line on Low Level DC Signal



$$e_x = e_{REF} \frac{R_{ac}}{R_{ab}}$$

POTENTIOMETRIC VOLTMETER

Figure 18 Potentiometric Type Voltmeter



R_s = Source Impedance

R_N = Input Impedance

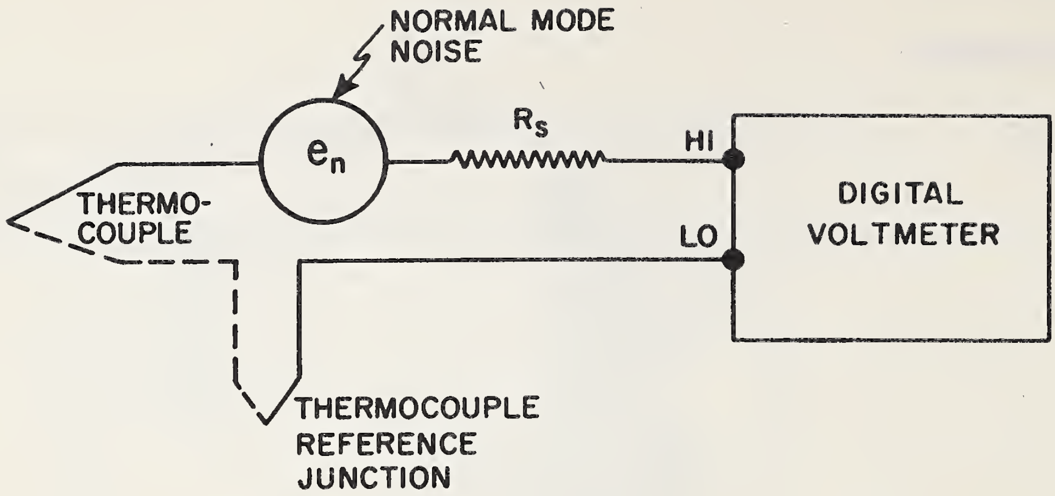
V_s = Source Voltage

V = Voltmeter Voltage

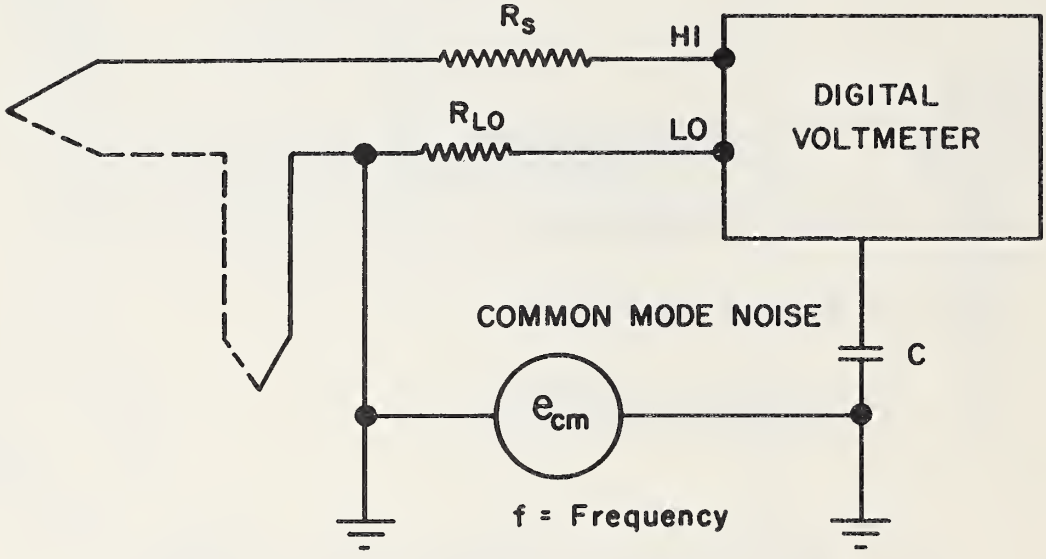
$$V = V_s \left(\frac{1}{1 + \frac{R_s}{R_N}} \right) \approx V_s \left(1 - \frac{R_s}{R_N} \right)$$

INPUT IMPEDANCE

Figure 19 Current-drawing Type (Non-Potentiometric) Voltmeter



A. NORMAL MODE REJECTION $= 20 \text{ Log}_{10} \dfrac{e_n}{\text{VOLTMETER ERROR}}$

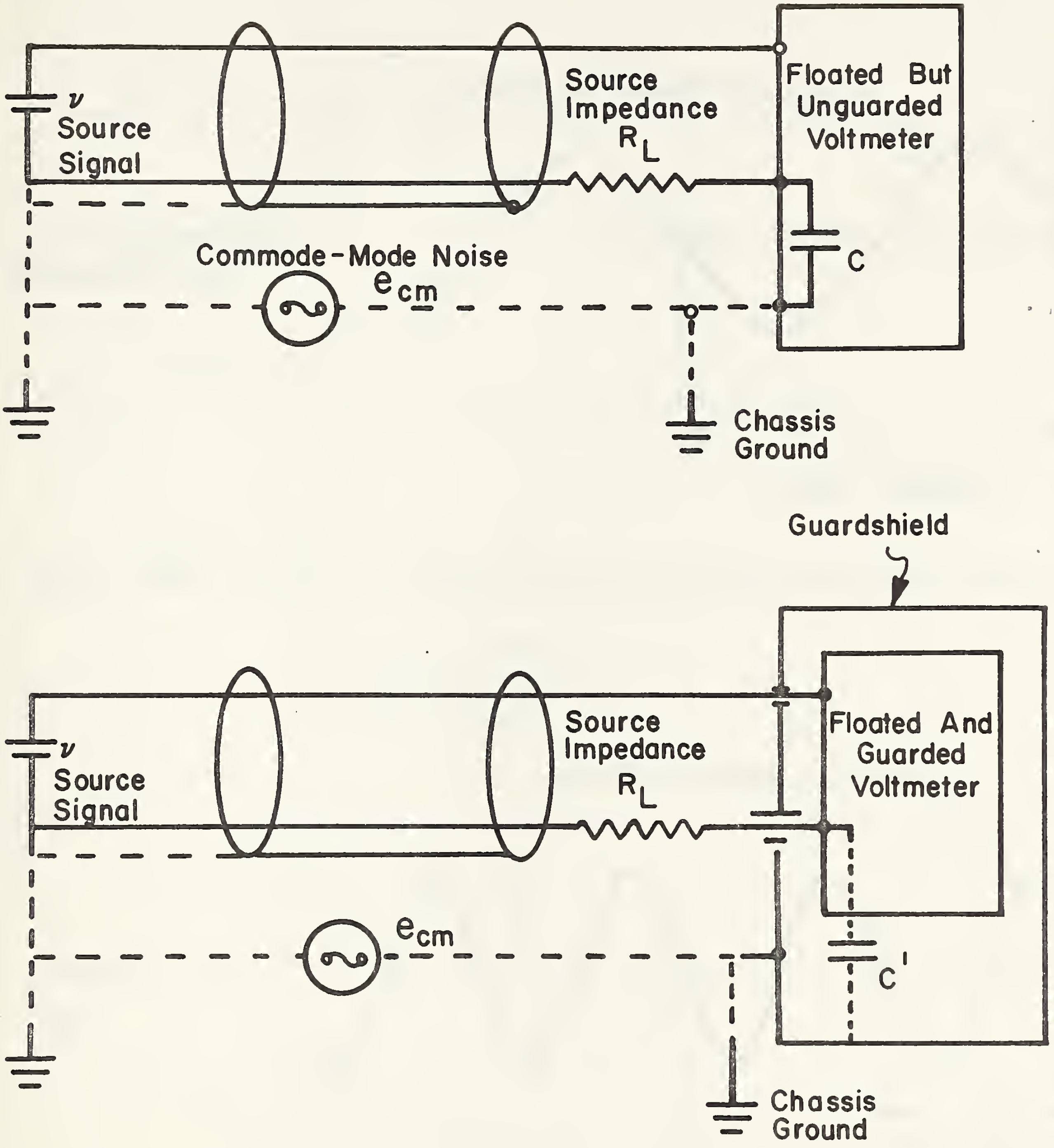


B. COMMON MODE REJECTION $= 20 \text{ Log}_{10} \dfrac{e_{cm}}{\text{VOLTMETER ERROR}}$

$$\approx 20 \text{ Log}_{10} \frac{1}{2\pi f C R_{LO}}$$

NOISE REJECTIONS

Figure 20 Common and Normal Mode Noise Rejection



Common-Mode Noise Rejection

$$\mathrm{CMNR} = 20 \operatorname{Log}_{10} \frac{1}{2\pi f C' R_L}$$

$C' \ll C$

Figure 21 Guarded and Unguarded Voltmeters

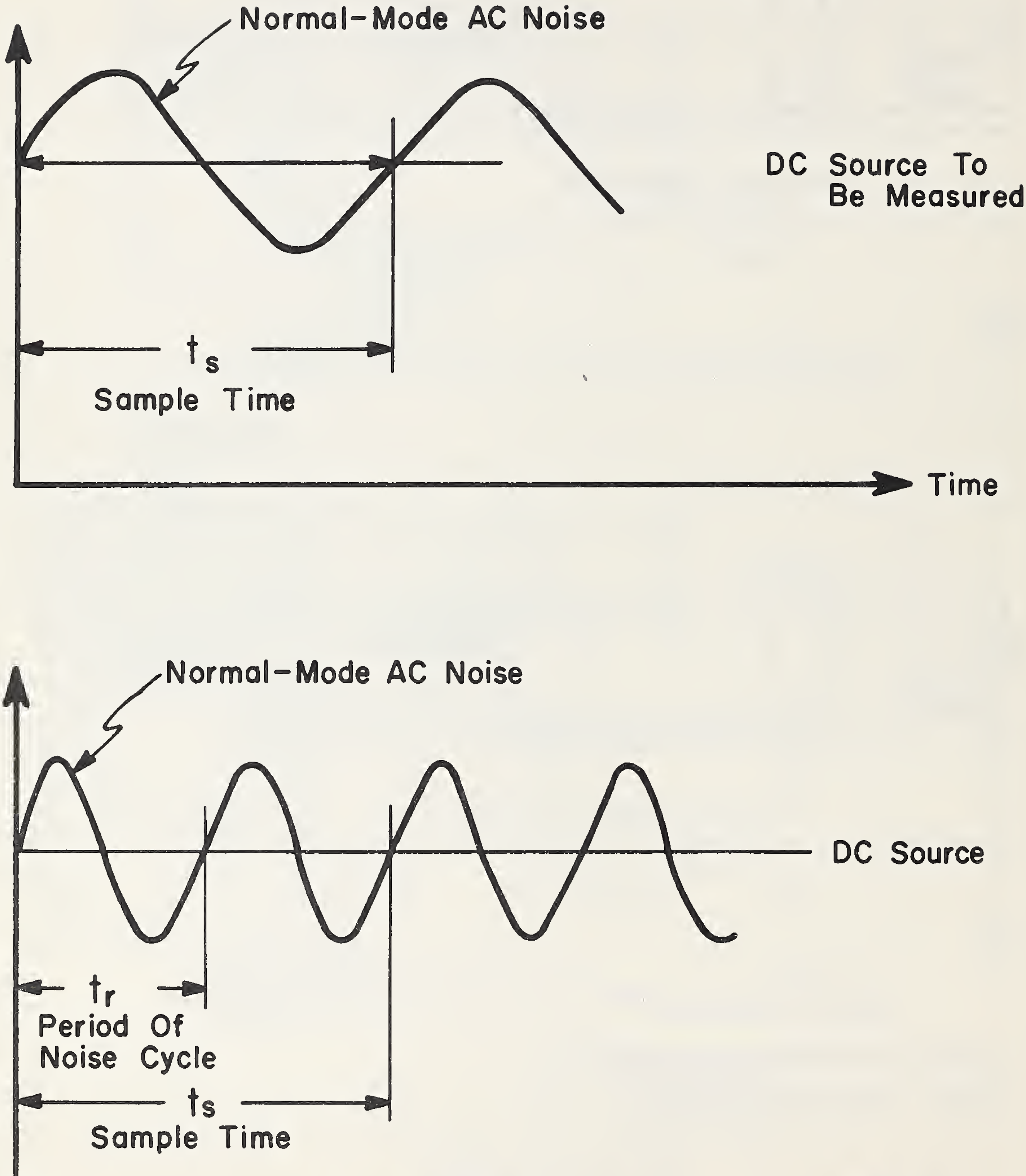
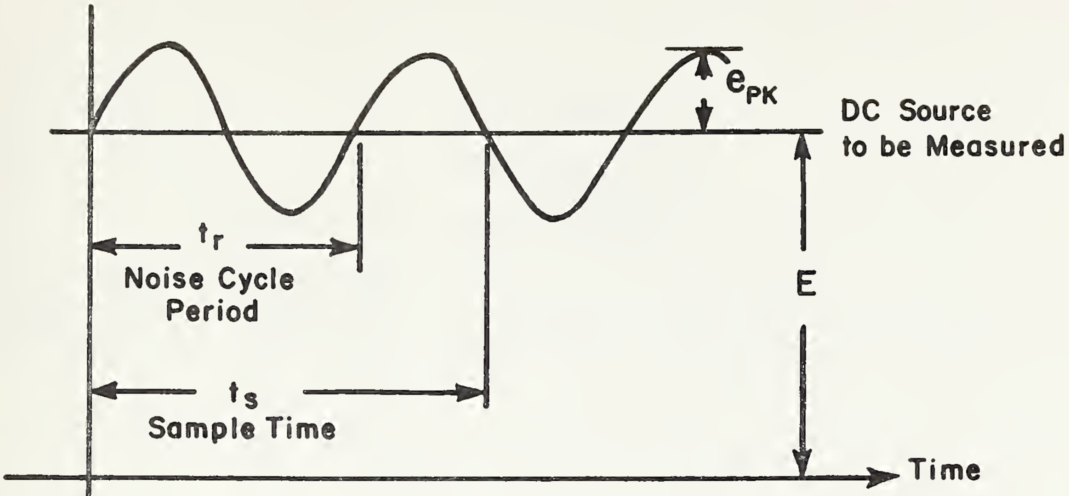


Figure 22 Normal Mode Noise Rejection



$$\frac{e_{NM}}{E} = \frac{\frac{e_{PK}\, t_r}{\pi}}{E \cdot t_s} \propto \frac{t_r}{t_s} = \frac{f_s}{f_r}$$

e_{NM} = Maximum Error

f_A = Sampling Frequency

f_r = Noise Frequency

Figure 23A Normal Mode Noise Rejection (db)

$$NR = 20 \log_{10} \frac{E}{e_{NM}} \propto 20 \log_e \frac{f_r}{f_s}$$

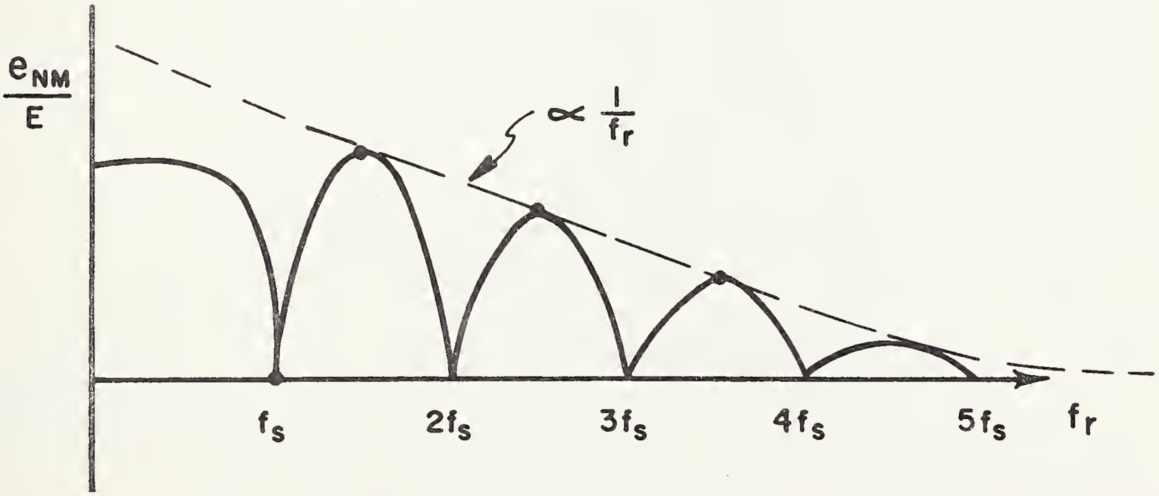


Figure 23B Integration of the Source Output to Reduce the Normal Mode Noise

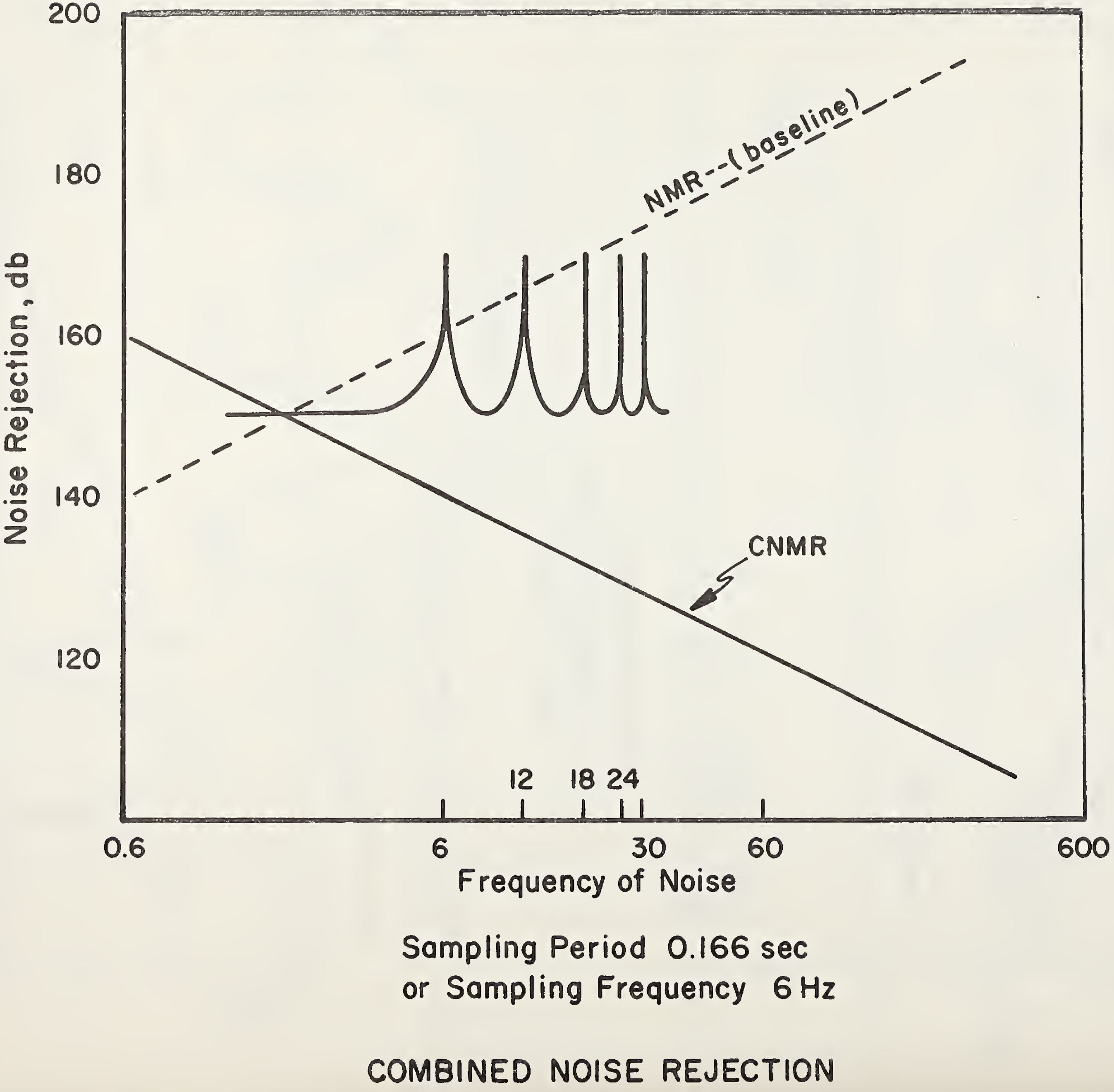


Figure 24 Overall Noise Rejection Characteristics

BCD-ASC II
TRANSLATION

CHARACTER		BCD			ASC II								OCTAL
	1	2	4	8	PARITY		4	2	1	4	2	1	
0	0	0	0	0			0	0					60
0	1	0	0	0	0		0	0			1	0	261
2	0	1	0	0	0		0	0			0		262
3	1	1	0	0			0	0			0	0	63
4	0	0	1	0	0		0	0		0	0	0	264
5	1	0	1	0			0	0		0		0	65
6	0	1	1				0	0		0	0		66
7	1	1	1		0		0	0		0	0	0	267
8	0	0	0	1	0		0	0	0				270
9	1	0	0	1			0	0	0			0	71
+							0		0		0	0	53
−							0		0	0		0	55
SPACE					0		0						240
CARRIAGE RETURN					0				0	0		0	215

Figure 25 ASC II Code for the Data Transmission Through Telephone Lines

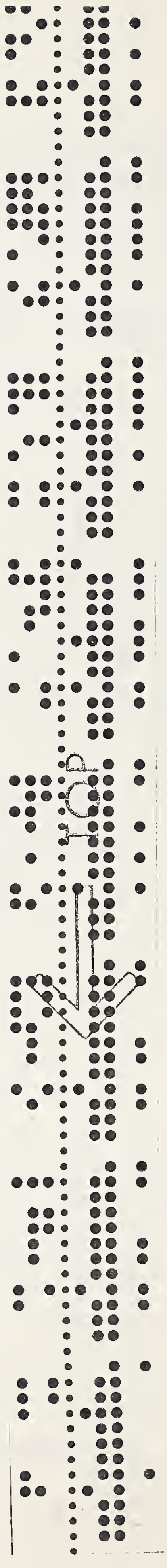
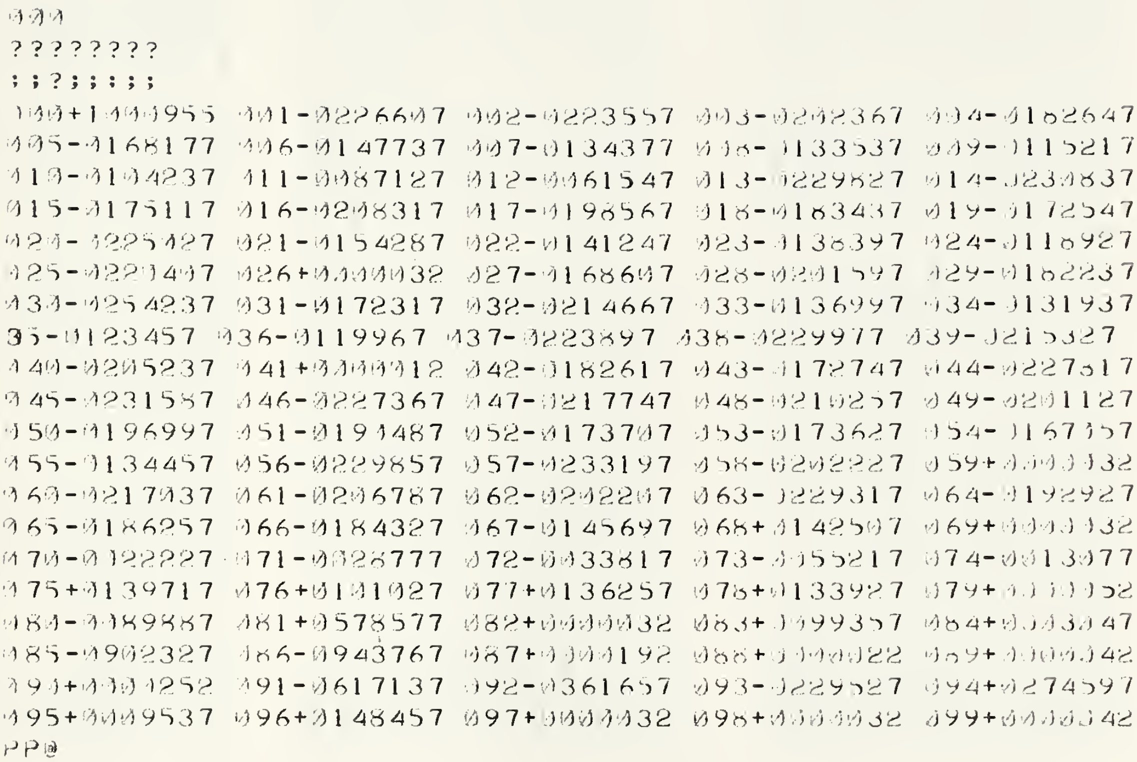


Figure 26 ASC II Punched on Paper Tape



```
000
????????
;;?;;;;;
000+1000955 001-0226607 002-0223557 003-0202367 004-0162647
005-0168177 006-0147737 007-0134377 008-0133537 009-0115217
010-0104237 011-0087127 012-0061547 013-0229827 014-0230837
015-0175117 016-0208317 017-0198567 018-0183437 019-0172547
020-0225427 021-0154287 022-0141247 023-0138397 024-0116927
025-0220407 026+0000032 027-0168607 028-0201597 029-0162237
030-0254237 031-0172317 032-0214667 033-0136997 034-0131937
35-0123457 036-0119967 037-0223897 038-0229977 039-0215327
040-0205237 041+0000012 042-0182617 043-0172747 044-0227517
045-0231587 046-0227367 047-0217747 048-0210257 049-0201127
050-0196997 051-0191487 052-0173707 053-0173627 054-0167157
055-0134457 056-0229857 057-0233197 058-0202227 059+0000032
060-0217037 061-0206787 062-0202207 063-0229317 064-0192927
065-0186257 066-0184327 067-0145697 068+0142507 069+0000032
070-0022227 071-0028777 072-0033817 073-0055217 074-0013077
075+0139717 076+0141027 077+0136257 078+0133927 079+0000052
080-0189887 081+0578577 082+0000032 083+0099357 084+0003047
085-0902327 086-0943767 087+0000192 088+0000022 089+0000042
090+0001252 091-0617137 092-0361657 093-0229527 094+0274597
095+0009537 096+0148457 097+0000032 098+0000032 099+0000042
PP@
```

Figure 27   Printout of a Teletype

Figure 28 Octal Listing of the Magnetic Tape, Which is a Copy of the Paper Punch Tape. This Tape is Read by UNIVAC 1108 Via CHAR(N)

```
PAGE:      5

555055505550 555055505550 555055505550 555055505550 555055505550 555055505550 555055505550 555055505550 555040404040 404040404040
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555040404043 454340435552 404341535143 464351435143 475340524040 404345434153 555240434153 514340434453 505347534052 404040434543
425355524043 415347534343 475340434753 405240404043 454343435552 404341534753 434346434253 475340524040 404345434453 555240434153
464347534043 454347535550 404040434543 454355524043 415343434453 445345434753 405240404043 454346435552 404342534253 514350534543
475340524040 404345434753 555240434253 434343434153 514347534052 404040434543 505355524043 425340434253 425342534753 405240404043
454351435342 404340434043 404340434343 425355504040 404346434043 555240434253 415347534043 434347534052 404040434643 415355524043
425340434643 475350534753 405240404043 464342535552 404342534043 425342534043 475340524040 404346434343 555240434253 425351434343
415347534052 404040434643 445355524043 415351434253 514342534753 555040404043 464345435552 404341535053 464342534543 475340524040
404346434643 555240434153 505344534343 425347534052 404040434643 475355524043 415344534543 464351434753 405240404043 464350535342
*****      170 WORDS IN BLOCK        2 *****


404341534453 425345434043 475340524040 404346435143 534240434043 404340434043 434342535550 404040434753 404355524043 404342534253
425342534753 405240404043 475341535552 404340434253 505347534753 475340524040 404347534253 555240434043 434343435053 415347534052
404040434753 434355524043 404345434543 425341534753 405240404043 475344535552 404340434153 434340434753 475355504040 404347534543
534240434153 434351434753 415347534052 404040434753 464353424043 415340434153 404342534753 405240404043 475347535342 404341534343
464342534543 475340524040 404347535053 534240434153 434343435143 425347534052 404040434753 514353424043 404340434043 404345434253
555040404043 505340435552 404340435053 514350535053 475340524040 404350534153 534240434543 475350534543 475347534052 404040435053
425353424043 404340434043 404343434253 405240404043 505343435342 404340435143 514343434543 475340524040 404350534453 534240434043
404343434043 445347535550 404040435053 454355524043 514340434253 434342534753 405240404043 505346435552 404351434453 434347534643
475340524040 404350534753 534240434043 404340434153 514342534052 404040435053 505353424043 404340434043 404342534253 405240404043
505351435342 404340434043 404340434453 425355504040 404351434043 534240434043 404340434253 454342534052 404040435143 415355524043
464341534753 415343434753 405240404043 514342535552 404343434643 415346434543 475340524040 404351434343 555240434253 425351434543
425347534052 404040435143 445353424043 425347534453 454351434753 555040404043 514345435342 404340434043 514345434343 475340524040
404351434043 534240434153 445350534453 454347534052 404040435143 475353424043 404340434043 404343434253 405240404043 514350535342
404340434043 404340434343 425340524040 404351435143 534240434043 404340434043 445342535550 404040404040 404040404040 405740404040
404040404040 404040404040 404040404040 404040404040 404040404040 404040404040 404040574040 404040404040 575740404040 404040404040
405655554040 404040404040 404055505550 555055505550 555055505550 555055505550 555055505550 555055505550 555055505550 404040404040
404040404040 404000000000
```

A Sample Operation of the Bit Reversal

4753

5347

101 011 100 111

010 110 111

2 6 7

7

Decoding List

UNIVAC/DIGIDATA	ASC II	DECIMAL NO
4043	60	0
4153	261	1
4253	262	2
4343	63	3
4453	264	4
4543	65	5
4643	66	6
4753	267	7
5053	270	8
5143	71	9

Figure 29 Decoding Scheme of the Magnetic Tape Data

```
WEEK OF    3 29 69
REMARKS
  DATE  3 /  1     TIME    030

CHAN NO       MV        DATA   REMARK       CHAN NO        MV        DATA    REMARK
    0  1000.6800  1000.0   REF              50        -2.6258     36.0    T
    1     -2.2002    55.5   T                51        -2.6430     35.2    T
    2     -2.1875    56.1   T                52        -2.6459     35.0    T
    3     -2.3214    50.0   T                53        -2.6285     35.8    T
    4     -2.4495    44.1   T                54        -2.6302     35.8    T
    5     -2.5253    40.6   T                55        -2.7098     32.1    T
    6     -2.5646    38.8   T                56        -2.2683     57.4    T
    7     -2.5078    41.4   T                57        -2.2591     52.9    T
    8     -2.5007    41.8   T                58        -2.6428     35.2    T
    9     -2.4893    42.3   T                59          .0003    149.9    T
   10     -2.5341    40.2   T                60        -2.5594     39.1    T
   11     -2.5443    39.8   T                61        -2.6151     36.5    T
   12     -2.6294    35.8   T                62        -2.6376     35.4    T
   13     -2.2108    55.0   T                63        -2.3717     47.7    T
   14     -2.2284    54.2   T                64        -2.6408     35.3    T
   15     -2.7376    30.8   T                65        -2.6386     35.4    T
   16     -2.5196    40.9   T                66        -2.6474     35.0    T
   17     -2.6043    37.0   T                67        -2.7307     31.1    T
   18     -2.7007    32.5   T                68          .9690     76.0    T
   19     -2.7415    30.6   T                69          .0003     76.1    T
   20     -2.3939    46.7   T                70         -.3963     58.3    T
   21     -2.7513    30.1   T                71         -.3343     61.1    T
   22     -2.7522    30.1   T                72         -.4719     54.9    T
   23     -2.7563    29.9   T                73         -.7769     40.9    T
   24     -2.7647    29.5   T                74         -.9358     33.6    T
   25     -2.2394    53.7   T                75         -.1606     24.5    T
   26       .0003   149.9   T                76          .0770     35.6    T
   27     -2.6423    35.2   T                77          .1224     37.7    T
   28     -2.5590    39.1   T                78         -.1557     24.7    T
   29     -2.6468    35.0   T                79          .0003       .0    **
   30     -2.6141    36.5   T                80          .0196      1.9    SOL
   31     -2.6470    35.0   T                81          .0003       .0    SOL
   32     -2.4477    44.2   T                82          .5610       .0    SOL
   33     -2.6509    34.8   T                83         2.1950       NW    WDD
   34     -2.6688    34.0   T                84          .0327      7.0    WDV
   35     -2.6851    33.2   T                85         1.0172      1.5    HF
   36     -2.7122    31.9   T                86         -.1995      -.3    HF
   37     -2.1903    56.0   T                87         1.2179      1.7    HF
   38     -2.2699    52.4   T                88          .0010       .0    HF
   39     -2.4465    44.3   T                89          .7775      1.2    HF
   40     -2.5599    39.0   T                90        -7.2002    -10.4    HF
   41       .0004   149.9   T                91          .5786       .8    HF
   42     -2.6527    34.7   T                92          .5562       .8    HF
   43     -2.6532    34.7   T                93        -2.2782     52.0    T
   44     -2.2441    53.5   T                94         2.3222      2.3
   45     -2.2431    53.6   T                95          .0922      2.9    RAIN
   46     -2.3516    48.6   T                96         1.9934     64.9     REF
   47     -2.4594    43.7   T                97         1.9043      2.1     UVR
   48     -2.5336    40.3   T                98          .0002       .0    ***
   49     -2.5988    37.2   T                99          .0003       .0    ***
```

Figure 30 Output Table of the Computer Program SOIL

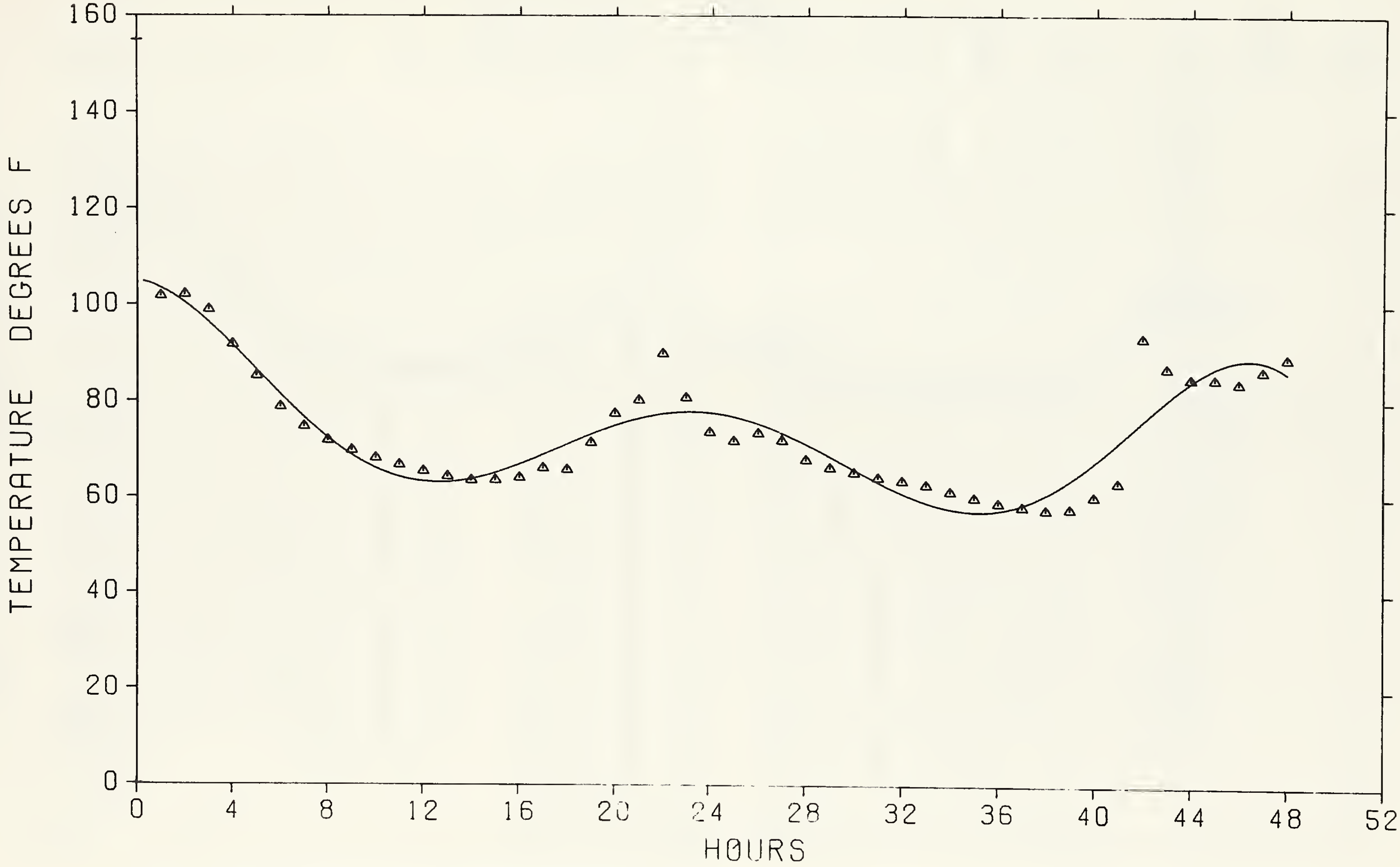


Figure 31 4"-Depth Temperature Under Asphalt Cover (Patch #1)

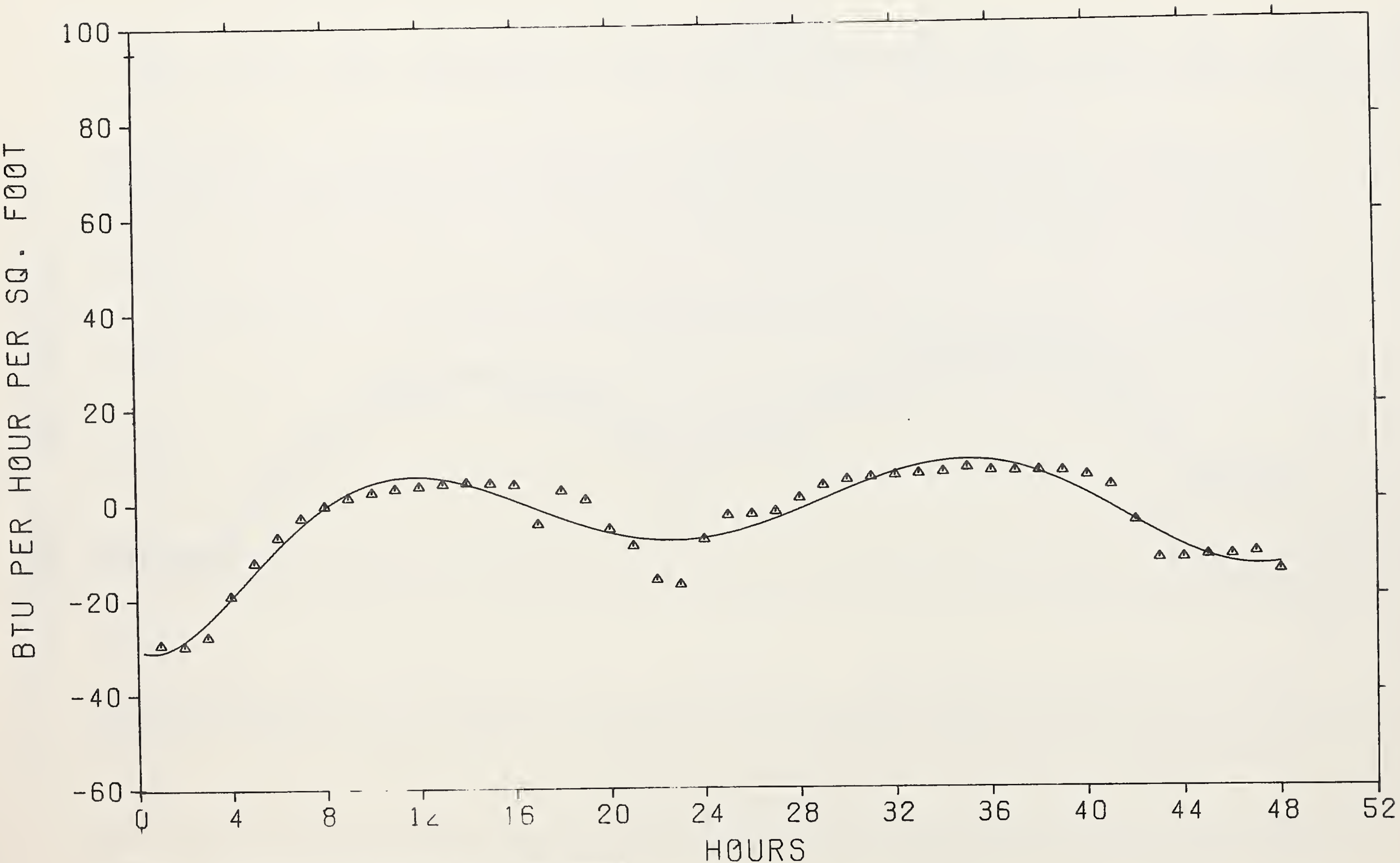


Figure 32 4"-Depth Heat Flow Meter Under Asphalt Cover (Patch #1)

Appendix 1

Specifications for
Automatic Data Acquisition System for Earth Temperature Measurement
(Contractual Research Under Office of Civil Defense,
Department of the Army, Contract OCD-OS-62-44, Unit 1211A)

This research contract calls for hourly measurement of undisturbed earth temperatures at selected depths for five sites during a period of two years, starting from late 1967. Also included in the study are the hourly measurements of air dry-and wet-bulb temperatures at four feet above the ground surface, and solar incident radiation and heat flux at the ground surface. Temperature measurements will be made by thermocouples (cold-junction compensation supplied by NBS) at ambient conditions.

It is contemplated at this moment that the data acquisition system will be housed in an underground bunker and the data acquired will be transmitted through telephone cable to a teletypewriter in Room B307, Building 226 of the National Bureau of Standards. The telephone cable distance is approximately one mile.

1. The system shall consist of a low-level scanner for millivolt signals from copper constantan thermocouples, integrating digital voltmeter (or an equivalent digital voltmeter capable of acquiring statistical average of one second sampling period), a coupler to the teletypewriter, and timer. The timer is to control the initiation of the scanning cycle as well as to identify the scanning cycle by providing identification signal.

The system shall be capable of accepting two external digital signals which will be compatible in electrical characteristics with the output from the digital voltmeter. The external system to produce two digital signals will be considered optional for this specification and the detail pertaining to this sub-system is explained later*.

2. A suggested sequence of the output will be scan identification, data from two external digital sub-systems, calibration data, followed by the channel information consisting of channel identification, polarity, data, decimal or exponent.
3. The paper tape shall be of ASC II code and shall have the following word format corresponding to each of 100 channel data: channel identification; 3 characters, polarity; one character, data; 6 characters, decimal; one character, and space; one character.
4. Each two wire input to the system shall be individually guarded and interchannel capacitance shall not exceed 0.5 pF. A random access mode of operation shall be provided within the scanner.

5. The integrating digital voltmeter (IDVM) shall have a sampling period of either one second or 0.166 second. If it is a successive approximation type, the digital voltmeter shall be capable of acquiring the best statistical estimate of average data for one second when operating under this integrating period of one second. The overall effective common mode rejection of the system shall be greater than 120 db and the normal mode rejection shall be greater than 35 db for all the frequency above 59 cps.
6. Since the system has to be operated unattended for a period of several weeks between the consecutive calibration checks, it is mandatory that it possess a small drift characteristic due to time and due to ambient temperature fluctuations. The input signal to the scanner is low level, (a few microvolts to a maximum of 10 millivolts). With respect to this input signal level, the required resolution, time stability and temperature stability shall be specified as follows:

System Resolution	0.001% or better (0.1 microvolt for 10 millivolt signal level).
Time Stability	0.05% per week or better 0.1% per month or better
Temperature Stability	± 0.10% per deg. C or better (± 10 microvolts for 10 deg. C change of ambient at 10 millivolt level).

7. The system shall include a ± 1 volt calibration source in a temperature controlled bath. The reference voltage shall have drift characteristics of less than 0.005% for 30 days and temperature coefficient of 0.003%/C for 10 to 50 C. This calibration voltage shall be provided to the input of the scanner and shall be recorded as the first channel of information for each scanning cycle.
8. The system shall have an input impedance of not less than 10 megohms for 10 MV signal range.
9. The time shall be provided to allow manual selection of time interval between the scan initiation. The time interval may be established at 30, 60, 120, or 240 minutes. When the selected amount of time has passed, the timer issues an "initiate" command to the scanner, which advances to the first channel of the 100-channel group. When all the channels have been recorded, the time system remains idle until the next "initiate" command is received. The timer

system shall include a digital counter which produces the scan identification number (4 digits) and feeds it into the digital system.

10. The system less the teletype unit shall be smaller than 36" high, 36" wide and 36" deep. The system shall be capable of normal operation for the environment of 20° ± 10 °C and 70° ± 20% RH.

11. The system less the teletypewriter shall be mounted in a rigid metal cabinet and the metal cabinet shall have four eyebolts at the top and four 2-1/2" wheels at the bottom for handling.

12. The vender shall inspect and test the system at the National Bureau of Standards and certify that it is in working condition within the requirement of this specification.

13. The vender shall warranty the entire system for one year from the date of acceptance by the National Bureau of Standards. Service shall be performed at the NBS by a fully qualified service engineer to be supplied by the vender within five days of notification.

14. Vender shall provide comprehensive instruction manuals including calibration and trouble shooting procedures, and complete parts lists.

15. Bidders are requested to provide a complete set of technical brochures describing major components of the system, which will be used by NBS to evaluate the proposal.

16. The entire system shall be delivered to the National Bureau of Standards (Gaithersburg, Maryland) and made operational within 120 calendar days from the date of purchase order.

*17. Due to the very much fluctuating nature of the solar incident radiation and ground surface heat flux, it is necessary to obtain hourly integrated values. A suggested method is to convert millivolt signal of ± 0-20 linearly into frequency of 0-1000 cpm and to totalize the hourly frequency by an electronic bi-directional counter of at least 6 digits. The counter will count up on positive signals and down on negative signals. The counter shall be automatically reset to zero, if necessary; at the end of the scanning cycle. The detail of this integrating system design will be left to the vender. This long integrating system, however, should be able to maintain 0.1% linearity and accuracy of reading over full range with ± 10% variation in line voltage. The timing of the system shall be such as to allow the completion of a fixed clock controlled integration period before the readiation and heat flux signals are recorded. That is if the timer is set on a 30 minute cycle integration of 29 minute values will be provided. At 60 minutes, 58 minutes and so on.

```
741 NDATA       0000 I 014736 NDAY        0000 I 014742 NHOUR       0000 I 000377 NO
001 NTAPE       0000 I 014752 NTEST       0000 I 014737 NYR         0000 R 014763 PV
612 REMK        0000 I 014726 SKIP        0010 R 000000 TCONF       0000 R 000622 TF
731 TIMEO       0000 I 014730 TPETST      0000 R 000217 V1          0000 R 014764 V2
765 WDV         0000 R 000363 YR
```

```
C
C
C
C
C      THIS PROGRAM READS DATA FROM MAG TAPE OR DATA CARDS
C
C        KCARD = BLANK SPACE FOR CARD INPUT
C        KCARD = 1 FOR TAPE INPUT
C      SKIP.. NUMBER OF BLOCKS TO BE SKIPPED ON OUTPUT TAPE BEFORE THE
C             PRESENT OUTPUT IS WRITTEN, WHICH SHOULD BE EQUAL TO MAXHR
C             OF THE PREVIOUS RUN.  (OUTPUT TAPE UNIT IS A)
C
C        MAXHR = MAXIMUM EXPECTED NUMBER OF HOURS ON DATA TAPE (UNIT B) + JCOUNT
C        JCOUNT = MAXHR OF PREVIOUS RUN
C         FOR 2ND DATA CARD-- (ALL INTEGERS)
C             MONTH = MONTH OF 1ST DATA SET IN COL 1-3
C             NDAY = DATE OF 1ST DATA SET IN COL 4-6
C             NYR = YEAR OF 1ST DATA SET IN COL 7-9
C             MDAY = NUMBER OF DAYS IN MONTH IN COL 10-12
C             NDATA = ALWAYS 100 IN COL 13-15
C             NTIME = TIME OF 1ST DATA SET IN COL 16-19
C      ONE CYCLE OF DATA CORRESPONCS TO 1324 CHARACTEPS
C      ONE RECORD OF TAPE CONTAINS 510 CHARACTERS
C
C
C
      DIMENSIONIDATA(15)/060,0261,0262,063,0264,065,066,0267,0270,071,
     1053,0255,0240,0215,0253/
      DIMENSION            ITABLE(14)/0,1,2,3,4,5,6,7,8,9,51,52,53,54/,NR
     2(12),ICHN(100), V1(100),YR(12),         NOTES(39),REM(100)
      DIMENSION REMK(8), TEMP(100),HF(10), IFOR(6000),      FOR(100)
      DATA (PEM(JH),JH=1,100)/3HREF,78*1HT,2H**,3*3HSOL,3HWDD,3HWDV,
     1  8*2HHF,
     2 1HT,2H  ,4HRAIN,6H REF  ,6H UVR  ,2*3H***/
      DATA(REMK(IK), IK=1,8)/2HN ,2HNW,2HW ,2HSW,2HS ,2HSE,2HE ,2HNE/
      INTEGER SKIP,     FSTCNT
      INTEGER TPETST
      COMMON III,NTAPE,NCNT
      III=510
      NTAPE=8
      CALL CLOCKT(TIMEO)
      JCOUNT = 0
      READ(5,7504) KCARD,SKIP,MAXHR,JCOUNT,TPETST
      WRITE(6,7504)KCARD,SKIP,MAXHR,JCOUNT,TPETST
 7504 FORMAT(10I7)
      FSTCNT = JCOUNT + 1
      READ(5,10) MONTH,NDAY,NYR,MDAY,NDATA,NHOUR,MIN
      WRITE(6,10)MONTH,NDAY,NYR,MDAY,NDATA,NHOUR,MIN
   10 FORMAT(5I3,2I2)
```

```
      CALL TPSKIP(7,SKIP)
      IDAY = NDAY
 7001 FORMAT(10F7.0)
      IF(KCARD.EQ.0) GO TO 7000
      DO 7766 L=1,2
      LL=(L-1)*13+1
      LJ=LL+12
      READ(5,13)(NOTES(JL),JL=LL,LJ)
 7766 WRITE(6,13)(NOTES(JL),JL=LL,LJ)
      IBLOCK=0
 7000 DO 7002 K=1,NDATA
 7002 ICHN(K)=K-1
      IF(KCARD.NE.0) GO TO 9114
 7004 DO 7003 L=1,2
      LL=(L-1)*13+1
      LJ=LL+12
      READ(5,13)(NOTES(JL),JL=LL,LJ)
 7003  WRITE(6,13) (NOTES(JL),JL=LL,LJ)
   13 FORMAT (1H1, 13A6,A2)
      READ(5,7001)(V1(K),K=1,NDATA)
      GO TO 7006
 9114 CONTINUE
      CALL CLOCK
      MTEST=0
      LSTNO = LSTNO + 1
      JCOUNT = JCOUNT + 1
      IF(JCOUNT.GT.MAXHR) GO TO 699
      MTEST = 0
   27 IN=0
   28 CALL CHAR(N)
      IF(III.EQ.510) IBLOCK=IBLOCK+1
      MTEST = MTEST + 1
 7520 FORMAT(10I2,2I10)
 7518 CALL CLOCKS(TIME)
      TIME=TIME-TIME0
      IF(TIME-50.) 7510,7511,7511
 7511 IF(MTEST.LT.1324) GO TO 7510
 7522 WRITE(6,7512) MTEST
      WRITE(6,7520) N,III,IBLOCK
 7512 FORMAT(1H1'TOO BAD YOU ARE IN TROUBLE, TAPE IS BAD, MTEST='I20)
      GO TO 31
 7510 IFOR(MTEST)=N
      IF(N.NE.IDATA(1)) GO TO 27
      IN=IN+1
      IF(IN.LT.2) GO TO 28
 8585 CALL CHAR(N)
      MTEST = MTEST + 1
      IFOR(MTEST) = N
      IF(N.EQ.IDATA(11)) GO TO 7010
      IF(N.EQ.IDATA(15)) GO TO 7010
      IF (N.EQ.IDATA(1)) GO TO 8585
      IF(IN.LT.3) GO TO 28
      GO TO 27
 7010 CONTINUE
 7008 LSTNO=0
 7009 DO 4 J=1,9
      CALL CHAR(N)
      DO 3 I=1,12
      IF(N.NE.IDATA(I))  GO TO 3
      NR(J)=ITABLE(I)
      YR(J)=NR(J)
      GO TO 4
    3 CONTINUE
    4 CONTINUE
       V1(1)=YR(1)*1000.+YR(2)*100.+YR(3)*10.+YR(4)+YR(5)/10+YR(6)/100.
 7501 ICHN(1)=0
   42 DO 100 K=2,NDATA
      DO 101 J=1,13
      CALL CHAR(N)
      DO 103 I=1,12
      IF(N.NE.IDATA(I)) GO TO 103
      NR(J)=ITABLE(I)
      YR(J)=NR(J)
      GO TO 101
  103 CONTINUE
  101 CONTINUE
      ICHN(K)=NR(1)*100+NR(2)*10+NR(3)
      ICHNX=ICHN(K)-ICHN(K-1)
       V1(K)=YR(5)*10+YR(6)+YR(7)/10.+YR(8)/100.+YR(9)/1000+YR(10)/10000
      IF(NR(4).EQ.52)  V1(K)=- V1(K)
  100 CONTINUE
      IF(TPETST.EQ.1) WRITE(6,7521)(V1(K),K=1,NDATA)
 7521 FORMAT(10F10.4)
C
C     CHANGE MILLIVOLTS TO DEG F
C
 7006 TEMP(1)=1000.
      DO 99 I = 2,68
      PV = ABS(V1(I))
      V2 = 2.711 - PV
      TEMP(I)=TCONF(V2)
   99 CONTINUE
      DO 98 I = 76,79
   98 TEMP(I) = TCONF(V1(I))
      TEMP(69) = TCONF(V1(69))
      DO 97 I = 70,75
      V2 = V1(I) + V1(69)
   97 TEMP(I) = TCONF(V2)
      FOR (81) = 99.4*V1(81)
      FOR(82) = 12.6*V1(82)
C
C     DETERMINE HEAT FLUX
C
      HF(1) = 1.44 * V1(86)
      HF(2) = 1.40 * V1(87)
      HF(3) = 1.37 * V1(88)
      HF(4) = 1.44 * V1(89)
      HF(5) = 1.51 * V1(90)
      HF(6) = 1.44 * V1(91)
      HF(7) = 1.37 * V1(92)
      HF(8) = 1.37 * V1(93)
C
C     DETERMINE WIND VELOCITY
C
      WDV = 214. * V1(85)
C
```

```
C       DETERMINE WIND DIRECTION
C
        WDD = V1(84)
        IF(WDD.GE..350) GO TO 61
        IK = 1
        GO TO 93
   61 IF(WDD.GE..450.AND.WDD.LT..550) GO TO 62
        IK=2
        GO TO 93
   62 IF(WDD.GE..650.AND.WDD.LT..770) GO TO 63
        IK=3
        GO TO 93
   63 IF(WDD.GE..900.AND.WDD.LT.1.10) GO TO 64
        IK=4
        GO TO 93
   64 IF(WDD.GE.1.50.AND.WDD.LT.1.90) GO TO 65
        IK=5
        GO TO 93
   65 IF(WDD.GE.1.15.AND.WDD.LT.1.30) GO TO 66
        IK=6
        GO TO 93
   66 IF(WDD.GE.4.50.AND.WDD.LT.6.00) GO TO 67
        IK=7
        GO TO 93
   67 IF(WDD.GE.2.50.AND.WDD.LT.4.40) IK=8
C
C       SET TEMP, HF, SOLAR, WIND INTO VARIABLE CALLED FOR (INFORMAT.C..)
C
   93 DO 400 JB=1,79
  400 FOR(JB) = TEMP(JB)
        FOR(80) = V1(80)
        FOR(83) = 0.
        FOR(84)=REMK(IK)
        FOR(85)=WDV
        DO 500  JC=1,8
        JB=85+JC
  500 FOR(JB) = HF(JC)
        FOR(94)=TCONF(2.711-ABS(V1(94)))
        FOR(95)=V1(95)
        FOR(96)=V1(95)*200./V1(96)/1750.
        PV = V1(97)
        V2 = 2.711 - PV
        FOR(97) = TCONF (V2)
        FOR(98)=V1(98)/0.925
        CALL CLOCKS(TIME)
        TIME=TIME-TIME0
        IF(TIME-150.) 7513,7514,7514
 7514 WRITE(6,7515) TIME
 7515 FORMAT(1H0'SOMETHING IS WRONG WITH DATA,ELAPSED TIME THIS RECORD
       1IS',F10.4)
        GO TO 70
C
C       WRITE OUT ANSWERS IN TABLE FORM
C
 7513 IF(KCARD.EQ.0) GO TO 43
        WRITE(7)JCOUNT,LSTNO,MONTH,NDAY,NYR,NHOUR,MIN,(FOR(J),J=1,100)
        WRITE(6,7502)JCOUNT,LSTNO
 7502 FORMAT(8H RUN NO=1I10,18H PRINTER LIST NO =  ,1I10 )
```

```
      IF(NHOUR.NE.0) GO TO 7503
      GO TO 70
 7503 IF(NHOUR.NE.12) GO TO 9113
   70 WRITE(6,20) MONTH,IDAY,NYR
   20 FORMAT('1','WEEK OF ',3I3)
      WRITE(6,21)
   21 FORMAT(1X,'REMARKS')
   45 WRITF(6,30)MONTH,NDAY,NHOUR,MIN,JCOUNT
   30 FORMAT (3X, 'DATE' , I3, ' /', I3, 4X,'TIME',2X,212,4X,'RUN NO.',
     1 15)
      WRITE(6,188) LSTNO
  188 FORMAT(33X,'PRINTER LIST NO =',I10/)
   43 WRITE (6,187)
  187 FORMAT (1X, 2('CHAN NO',5X,'MV',5X,'DATA  REMARK', 4X))
      DO 1200 IL=1,33
 1200 WRITE(6,201)ICHN(IL),V1(IL),FOR(IL),REM(IL),ICHN(IL+50),V1(IL+50),
     1 FOR(IL+50),REM(IL+50)
  201 FORMAT( 2(I6,F11.4, F7.1, 2X, A5, 4X))
      WRITE(6,203) ICHN(34),V1(34), FOR(34), REM(34), ICHN(84), V1(84),
     1 FOR(84), REM(84)
  203 FORMAT(I6,F11.4, F7.1, 2X,A5, 4X, I6, F11.4, 5X,1A2, 2X, A5,4X)
      DO 1201 IL=35,50
 1201 WRITE(6,201) ICHN(IL),V1(IL), FOR(IL), REM(IL), ICHN(IL+50),
     1 V1(IL+50), FOR(IL+50), REM(IL+50)
      WRITE(6,204)
 204  FORMAT(1H1)
      IF(TIME-50.) 7516,7516,7517
 7516 IF(KCARD.EQ.0) GO TO 7000
C     ADVANCE TIME BY ONE HOUR
C
 9113 NHOUR=NHOUR+1
      IF(NHOUR.LT.24) GO TO 31
C
C     START NEW DAY
C
      NHOUR=0
C
C     ADVANCE DATE BY ONE
C
      NDAY = NDAY + 1
C
C     CHECK FOR LAST DAY OF MONTH
C     SET MDAY EQUAL TO NUMBER OF DAYS IN MONTH
C
      IF(NDAY.LE.MDAY) GO TO 31
      NDAY = 1
C
C     START NEW MONTH
C
      MONTH = MONTH + 1
      IF(MONTH.LT.13) GO TO 31
      MONTH = 1
      NYR=NYR+1
   31 CONTINUE
      MXCNT=JCOUNT-1
      NCNT=MXCNT-FSTCNT+1
      IF(TIME-50.) 7523,7523,699
 7523 IF(KCARD.EQ.1) KPAT=1
```

```
      IF(KCARD.EQ.0) KPAT=2
      GO TO (9114,7000),KPAT
  699 CALL CLOCK
      NCNT=NCNT+1
      DO 698 J=1,NCNT
  698 BACKSPACE 7
      CALL TAP(NCNT)
 7517 STOP
      END
      SUBROUTINE CHAR(N)
      COMMON III,NTAPE,NCNT
      DIMENSION INCOME(510),INPUT(170)
      IF(III.NE.510) GO TO 2
      NEOF = 0
   12 CALL NTRAN(NTAPE,2,170,INPUT,L)
    1 IF (L+1),1
      IF (L) 5
      I=1
      DO 10 J=1,510,3
      INCOME(J)=(AND(FLD(6,6,INPUT(I)),15)*16)    +
     1(AND(FLD(0,6,INPUT(I)),15))
      INCOME(J+1)=(AND(FLD(18,6,INPUT(I)),15)*16) +
     1(AND(FLD(12,6,INPUT(I)),15))
      INCOME(J+2)=(AND(FLD(30,6,INPUT(I)),15)*16)
     1+(AND(FLD(24,6,INPUT(I)),15))
   10 I=I+1
      III=0
    2 III=III+1
      N=INCOME(III)
      RETURN


    5 N=-1
      WRITE(6,11)L
      IF(L.NE.-2) GO TO 13
      IF(NEOF.GT.2) GO TO 13
      NEOF = NEOF + 1
      CALL NTRAN (NTAPE,22)
      GO TO 12
   11 FORMAT(17H0 TAPE ERROR    L=I10)
   13 IF(NCNT.EQ.0) STOP
      DO 698 J=1,NCNT
  698 BACKSPACE 7
      CALL TAP(NCNT)
      STOP
      END
      SUBROUTINE TAP(NRUN)
      DIMENSION FOR(100) , REMK(8)
      DATA (REMK(IK), IK=1,8)/2HN ,2HNW,2HW ,2HSW,2HS ,2HSE,2HE ,2HNE/
      DO 2 M=1,NRUN
      READ(7)JCOUNT,LSTNO,MONTH,NDAY,NYR,NHOUR,MIN,(FOR(J),J=1,100)
      WRITE(6,3)JCOUNT,LSTNO,MONTH,NDAY,NYR,NHOUR,MIN
 3    FORMAT(10I7)
      DO 9 IK=1,8
      THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF(FOR(84).EQ.REMK(IK))FOR(84)=IK
 9    CONTINUE
 2    WRITE(6,4)(FOR(K),K=1,100)
 4    FORMAT(10F10.1)
      RETURN
      END
```

```
C     TEMPERATURE (IN DEGREES CELSIUS) USING A FOURTH DEGREE EQUATION
C     THIS SUBROUTINE WILL CONVERT A THERMOCOUPLE EMF (IN MILLIVOLTS) INTO
C     FITTED TO TABLE 10 IN NBS C561(COPPER-CONSTANTAN)
C     IF TCONF IS USED AS THE ENTRY THE TEMPERATURE WILL BE IN
C     DEGREES FAHRENHEIT
      FUNCTION TCON (X)
      DIMENSION A(5), B(5)
      DATA (A(N),N=1,5)/13.2028,-35.5181,46.33851,38.48602,0./,
     1    (B(N),N=1,5)/0.,52.8112,-106.5543,92.67702,38.48602/
      M=0
    1 IF ((X.GT.-5.4).AND.(X.LT.20.9)) GO TO 3
      TCON = 9999.9
      RETURN
    3 T=X*(0.0314-0.000755*X)
    4 E=A(1)
      S=B(1)
      DO 5 J=2,5
      E=A(J)+T*E
    5 S=B(J)+T*S
      D=X-E
      IF (ABS(D).LT.1.E-6) GO TO 10
      T=T+D/S
      GO TO 4
   10 TCON=1000.*T
      IF (M.EQ.1) TCON=1.8*TCON+32.
      RETURN

      ENTRY TCONF(X)
      M=1
      GO TO 1
      END
      SUBROUTINE TPSKIP(UNIT,SKIP)
      INTEGER UNIT,SKIP
      IF(SKIP)1,2,3
    1 SKIP = -SKIP
      DO 4  J=1, SKIP
    4 BACKSPACE  UNIT
      GO TO 2
    3 DO 5  J=1,SKIP
    5 READ(UNIT)
    2 RETURN
      END
```

Foundation Test Service, Inc.
SUBSOIL INVESTIGATIONS • TEST BORINGS • SOIL LABORATORY TESTING

JAMES J. SCHNABEL, P. E.
President

ERNEST WINTER, P. E.
DAVID F. DAVIS
Vice Presidents

January 24, 1968

National Bureau of Standards
Plant Division
Building 301, Room A-100
Washington, D. C. 20234

Attention: Mr. D. M. Trumble

Subject: Contract M67276 (S-462247-68)
Subsoil Investigation and Soil Testing,
Earth Temperature Instrumentation
Facility, Gaithersburg, Maryland

Gentlemen:

Submitted herewith are three copies of the report for the above contract with your office.

The test boring, location plan and soil test data are indicated by Drawing M67276-1 and the enclosed graph.

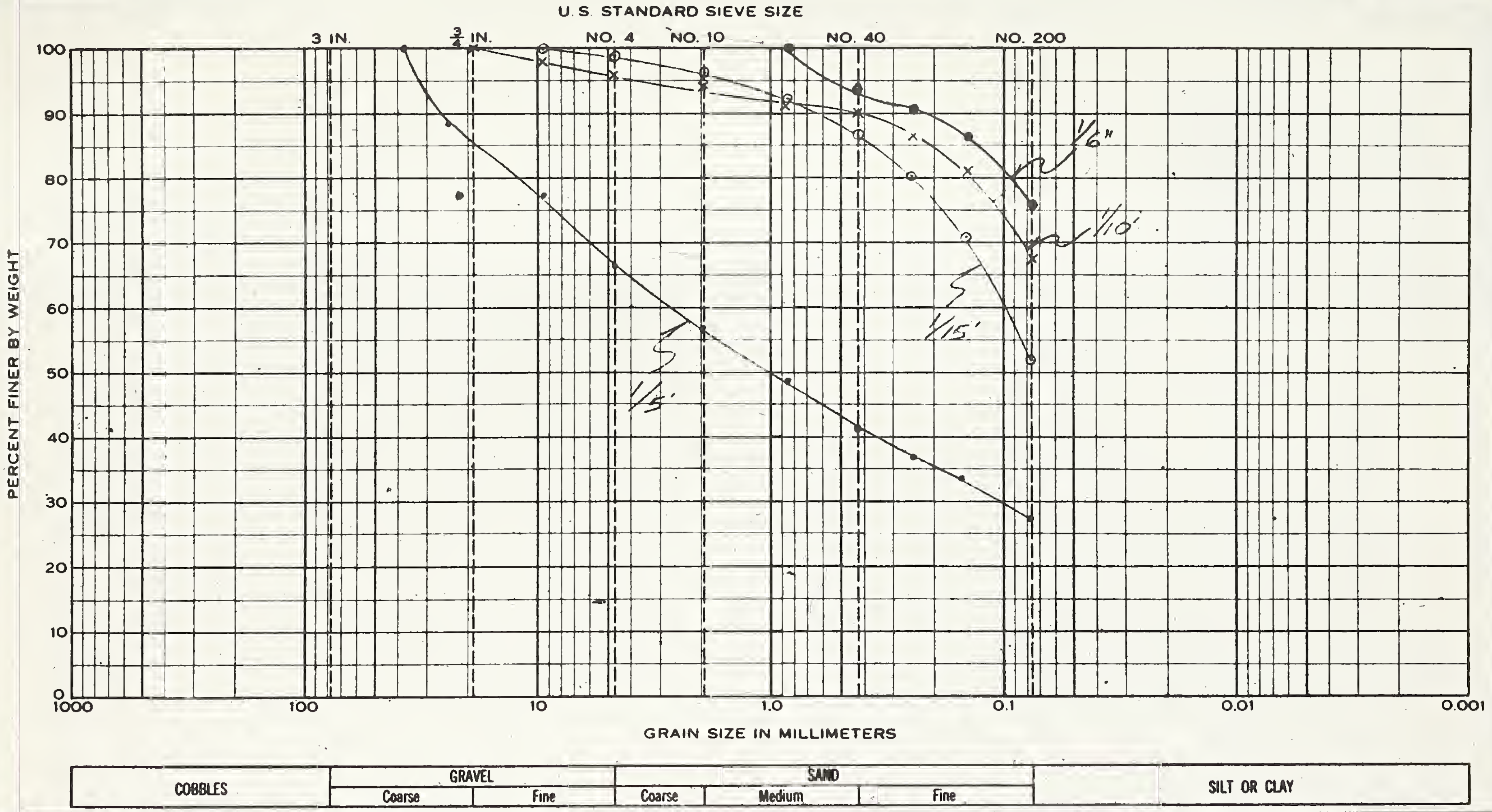
We appreciate the opportunity to be of service.

Very truly yours,

FOUNDATION TEST SERVICE, INC.

Ernest Winter
Vice President

EW:cv



Boring No.	Sample Depth	Classification	NatWC	LL	PL	PI
1	5'	FINE SILTY SAND, SOME ROCK FRAGS, BROWN	14.1	28.0	NP	NP
1	10'	FINE SANDY SILT, TRACE MICA, BROWN	12.4	-	NP	NP
1	15'	FINE SANDY SILT, TRACE MICA, BROWN & GRAY	11.1	23.8	NP	NP
1	0'-6"	FINE SANDY SILT, TRACE MICA, BROWN	16.6	31.0	NP	NP

GRADATION CURVES

FOUNDATION TEST SERVICE, INC.

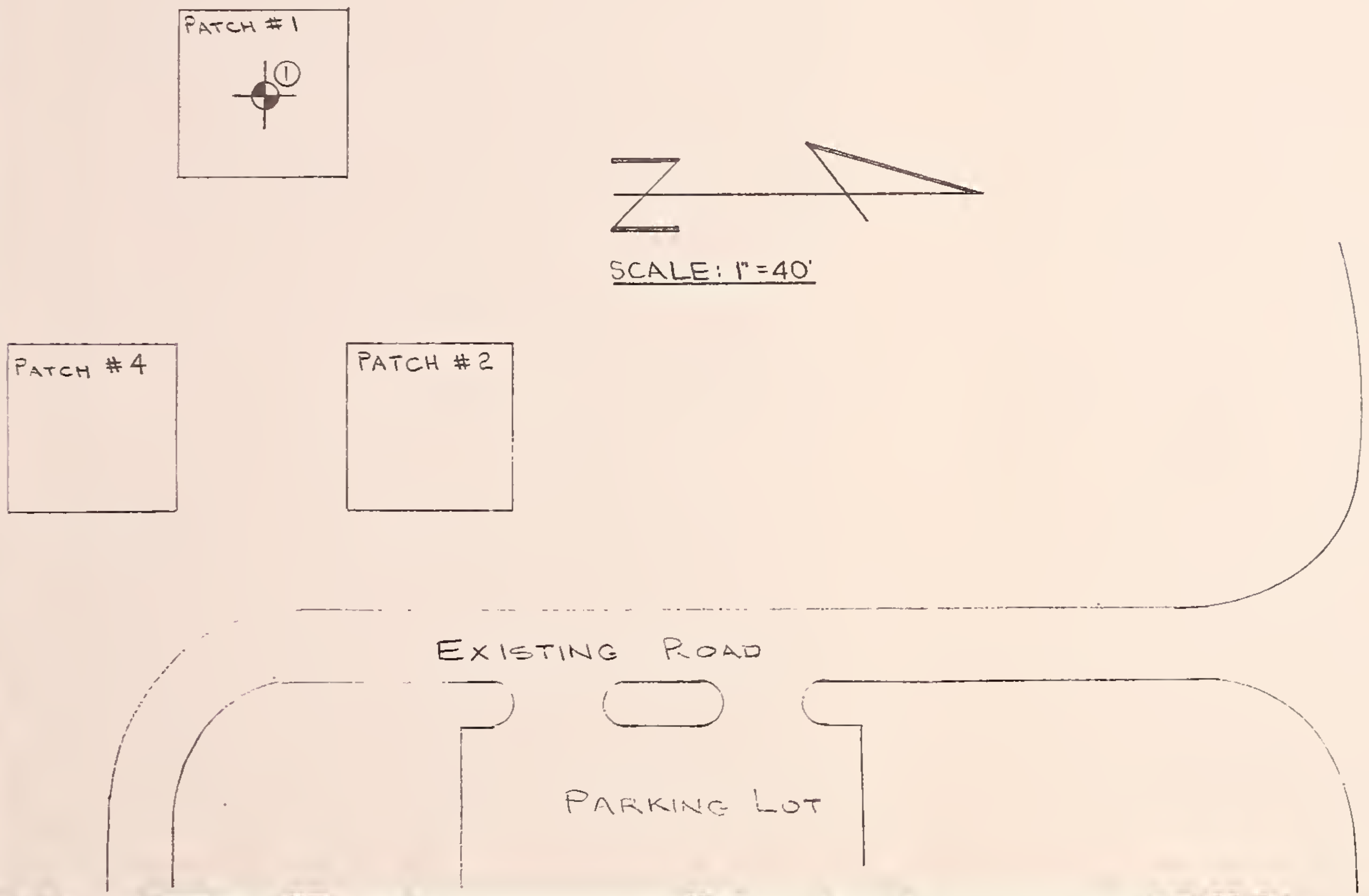
Project: EARTH TEMPERATURE INSTRUMENTATION FACILITY

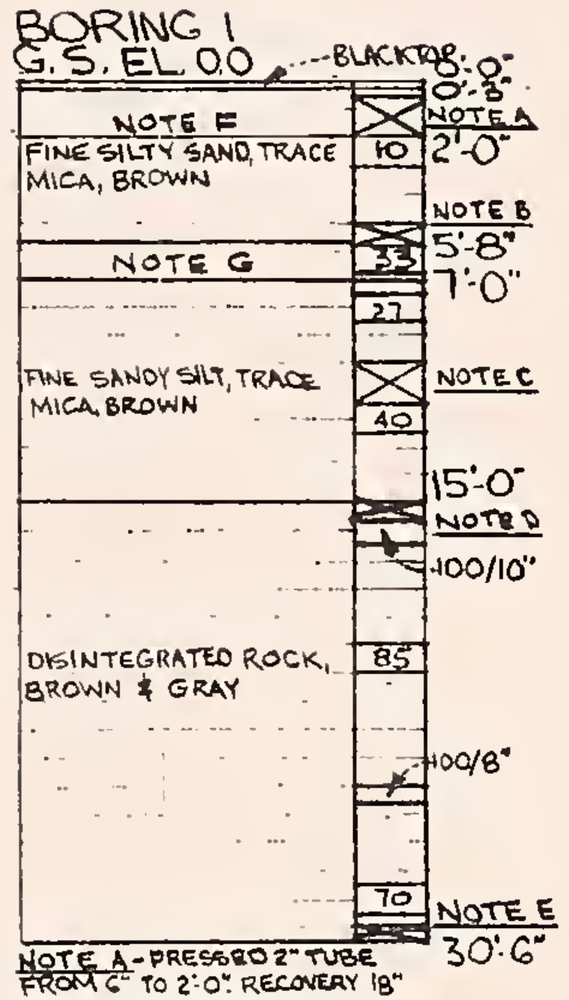
Contract No.: M67276

Date: JAN. 24, 1968

GENERAL NOTES

1. Number in right hand column of boring log indicates blows required to drive 2 In. O.D., 1⅜ In. I.D. sampling spoon one foot, using 140 pound hammer falling 30 inches.
2. Classification of soil is by visual inspection and is in accordance with the Unified Soil Classification System.
3. Estimated ground-water levels indicated by ▼ ; these levels are only estimates from available data and may vary with precipitation, porosity of the soil, site topography, etc.
4. BORING DRILLED BY MECHANICAL AUGER WITHOUT USE OF DRILLING WATER.
5. BORING LAYOUT FURNISHED.





NOTE A - PRESSED 2" TUBE FROM 6" TO 2'-0". RECOVERY 18"

NOTE B - PRESSED 2" TUBE FROM 5'-0" TO 5'-9". RECOVERY 9"

NOTE C - PRESSED 2" TUBE FROM 10'-0" TO 11'-6". RECOVERY 17"

NOTE D - DROVE 2" TUBE WITH 140 LB. WEIGHT - 20 BLOWS FROM 15'-0" TO 15'-8" RECOVERY 8"

NOTE E - DROVE 2" TUBE WITH 140 LB. WEIGHT 40 BLOWS FROM 30'-0" TO 30'-6" NO RECOVERY

NOTE F - FINE SANDY SILT, TRACE MICA & CLAY, BROWN

NOTE G - FINE SILTY SAND & DISINTEGRATED ROCK FRAGMENTS, TRACE MICA, GRAY

WATER LEVELS

ENCOUNTERED WATER AT NONE

ON COMPLETION AT NONE

OBSTRUCTION, NO READING
WATER AT — AFTER 24HRS

NOTE - DRILLED ALTERNATE HOLE ADJACENT TO BORING NO 1 TO DEPTH 32 FT.

TEST BORING REPORT

Foundation Test Service, Inc., Washington, D. C.

Project: EARTH TEMPERATURE INSTRUMENTATION FACILITY
Date: JANUARY 24, 1968
Location: NATIONAL BUREAU OF STANDARDS
Drawing No.: M67276-1
For: NATIONAL BUREAU OF STANDARDS
Vertical Scale: 1" = 8'-0"
Architect:
Engineer:

SOIL TEST DATA

BORING No.	SAMPLE DEPTH	SOIL CLASSIFICATION	NATURAL DRY DENS. P.C.F	NATURAL MOISTURE %	ATTERBERG LIMITS L.L.	P.L.	P.I.	REMARKS
1	0'-6"	FINE SANDY SILT, TRACE MICA, BROWN (ML)	94	16.6	31.0	N.P.	N.P.	SEE GRADATION CURVE
1	5'-0"	FINE SILTY SAND, SOME ROCK FRAGMENTS, BROWN (SM)	118	14.1	28.0	N.P.	N.P.	SEE GRADATION CURVE
1	10'-0"	FINE SANDY SILT, TRACE MICA, BROWN (ML)	115	12.4	N.P.	N.P.	N.P.	SEE GRADATION CURVE
1	15'-0"	FINE SANDY SILT, TRACE MICA, BROWN & GRAY (ML)	113	11.1	23.8	N.P.	N.P.	SEE GRADATION CURVE

Notes:
1. SOIL TESTS IN ACCORDANCE WITH APPLICABLE ASTM. STANDARDS
2. SOIL CLASSIFICATIONS IN ACCORDANCE WITH UNIFIED SOIL CLASSIFICATION SYSTEM.
3. N.P. INDICATES NON-PLASTIC.

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS